NUCLEAR ENGINEERING VOL. 6 NO. 62 JULY, 1961

The Research Group

WHEN visiting Harwell in June it is perhaps only natural that one should draw analogies with other rural activities and, following the latest reorganization within the U.K.AEA, the one particular aspect of horticultural practice that immediately springs to mind is pruning. In the reorganization, the Research Group surrendered control of the Atomic Energy Establishment at Winfrith, and since then has formally transferred many of its accelerator and electronics staff to the National Institute for Research in Nuclear Science. In area and in staff, these moves constitute a considerable reduction, and the Group's present plans do not anticipate an increase in resources (once Culham is fully established) and its future programme is planned upon a fixed complement. There is evidence, also, not only of the removal of major limbs, but of the steady pruning of irrelevant and extravagant shoots within the main bush (the decision to abandon the construction of ICSE last year may be taken as an example). As a result it can be expected that, as with the vine and the fig, the restriction in room and the careful cutting-out of non-essentials will see more prolific fruiting in the future.

It is possible now to see more clearly the functions of the Group in the general context of the Authority's development programme. In the words of Dr. Vick, the present director of Harwell, these are to carry out fundamental, basic and a certain amount of applied research in the general field of the peaceful applications of nuclear energy (including radioisotopes). The main task is to provide firm scientific and technical foundations on which much of the future development, design and production work of the Authority will rest. Reactor physics and engineering relating to specific reactor systems are the responsibility of the Reactor Group, but much of the work on the properties of the materials to be used in these systems is still carried out at Harwell. Full use is made of the materials testing reactors and other research reactors, which leads to special responsibilities in the fields of nuclear and solid state physics, chemistry and metallurgy and related subjects, including theoretical aspects. The electronics division carries out research and development work for the whole Authority (excluding defence and reactor instrumentation) and the health physics work is of wide implications.

Although the distinction between academic and applied research is difficult to make, it is estimated that some 20% of the effort at Harwell (where the annual operating budget is £15 million) will be devoted to work which is not specifically related to the atomic energy programme. As an example of such work one might cite the experiments undertaken to prove the relativity concept that time is a function of acceleration (or gravitation). This is not an excessive proportion, particularly when it is appreciated that it is the policy that there should be a reasonable flux of top-class research workers through the establishment, and in order to attract the best people, and continually provide a new source of scientific inspiration, the academic attractions of the work must be high. This presupposes, of course, that applied research is not regarded as a poor relation of pure research and that the academic workers also make their contribution to the programme. Otherwise one becomes sceptical of the assertion that there is no intention of Harwell being competitive with the Universities, but collaboration with them encouraged and activities confined, as far as possible, to those where the special facilities or techniques at Harwell are necessary, or where the material is classified in some way.

It is possible, incidentally, that a more generous interpretation will be taken in the future of what can be properly regarded as unclassified, and that Harwell will be less self-conscious about commercial security than the rest of the Authority; the amount of military security involved can be considered negligible. The description by Mr. Adams, the director of the Culham CTR laboratory, that Culham was to be an open establishment is also welcome, although the cynic may perhaps retort that this only serves to show how far we are in time and technology from a practical fusion reactor.

The Culham establishment is, at the moment, at a fairly early stage of construction but the CTR programme now has a much more solid look about it than it had at the time of the Zeta publicity fiasco. Following this, and the departure of a number of senior men abroad the impression was given that the bottom had been knocked out of the CTR programme. But, although it has passed through a period of disorganization much valuable work has been done at Harwell over the past two years both scientifically and technologically, as evidenced by the defining of the energy loss mechanisms from a pinch discharge (at low pressures by particles and at higher pressures by line radiation from impurities), the development of vacuum techniques allowing pressures of 10^{-9}-10^{-10} mmHg to be achieved

in big systems, the intensive diagnostic work that has gone on, and by the broadening of the programme to include mirror geometries. The general international collaboration in this field is another pleasing feature. One does wonder, however, if we are not neglecting the enormous potential of the direct conversion systems which are receiving intensive study at various establishments in the United States, although Harwell may not be the right place to do it.

At Harwell so diverse are the activities that in a short comment it is not possible even briefly to review the many experiments being conducted at the establishment. Some can be lumped quite simply into single categories such as research into the fundamental properties of materials the measurement of nuclear constants and so on, but not in terms of specific reactor problems although a good deal of the work, on graphite for example, is quite closely related to the immediate current problems of the civil programme. Now that the Reactor Group, with its own development establishments, has responsibility for the development of reactor systems, it is a quite deliberate policy that Harwell should be investigating generally applicable techniques and phenomena such as coated particles for fuel elements, plutonium technology, research into the treatment of radioactive effluent and so on. Dr. Vick has also made a point of the closeness of collaboration not only with the Reactor Group but also with the CEGB and industry.

From the long term viewpoint this division of responsibilities, with Harwell probing into general new channels, abandoning some, pressing on with others, and bombarding the Reactor Group with bright ideas which one hopes would be carefully considered in the context of its reactor systems development seems very reasonable. It is always more comfortable if the fundamental work is leading the practical exploitation. What, however, is to be the programme until this equilibrium position can be established? Desirable as it may be to avoid tying up staff on work on specific reactor systems, how is the gap to be filled between the very long term systems and the present Magnox stations? There is evidence of a great deal of work that will be directly applicable to the high temperature gas cooled reactor and the fast reactor. The AGR also is receiving its share of attention but in the light of the generally voiced CEGB opinion that they are unlikely ever to build an AGR for power production, can the Research Group cheerfully leave to the Reactor Group the evolution of an alternative system or stand back with equanimity if such a system is not forthcoming? Harwell is in fact, doing work on such potentially important subjects as burn-out of elements in channels cooled by boiling water, but would it not be better, at this point in time, if work such as this were specifically directed at a reactor project?

We appreciate that it is not the job of the Research Group to tell the Reactor Group what to do. What we do suggest is that an alternative system to the AGR should be chosen in the light of existing evidence and the further fundamental research relating to this system undertaken on a project basis rather than in a general context. More and more, one becomes nervous of having the whole of one's thermal eggs in a graphite basket and it may well be that a much rejuvenated Research Group is better able to initiate a new technology than the Reactor Group still struggling to find its feet.

Personnel Protection

THE establishment of maximum permissible levels and operational codes of practice for the safe handling of radioactive material has proved to be a protracted business and in many areas, such as the sea disposal of waste, general agreement is unlikely to be forthcoming for some time. The subsequent translation into legislative terms once technical agreement has been reached is also a lengthy process but much has now been done, and not only is international agreement close or complete on most aspects which affect the run-of-the-mill user of radioactive material, but also throughout the world national regulations are coming into force which give him clear guidance as to its control and the protection of personnel.

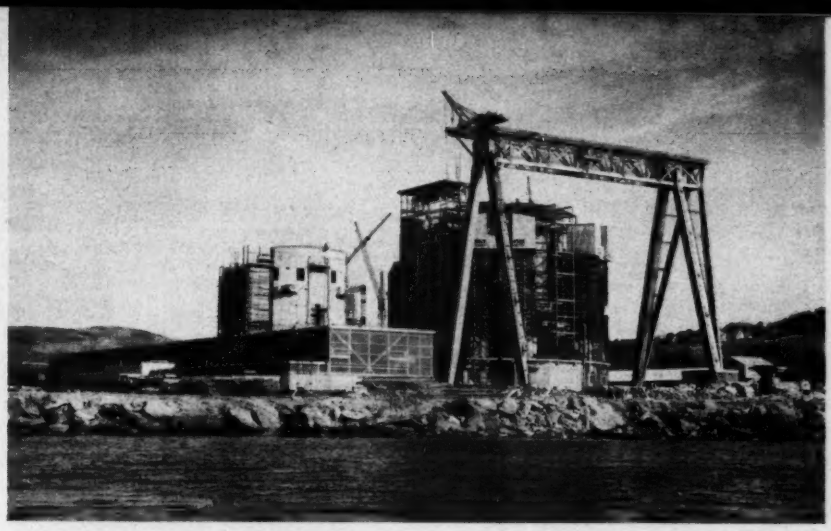
The IAEA, leaning heavily on the guidance of the ICRP and the atomic energy and health authorities in the member states, has been steadily working on the problems of co-ordination and at present is engaged on drawing up a final draft of its Basic Safety Standards which it is hoped will be submitted to the board of governors at the end of the year. The draft is being prepared by an international panel under Professor Bugnard of France and is concerned with two aspects, viz: the prescription of maximum levels of exposure, and fundamental operational principles. The Agency has also initiated work on detailed operational standards relating to the handling of radioisotopes, transport of radioactive materials, disposal into fresh water and the sea, as well as on the construction research reactors and critical assemblies (later to be followed by work on power reactors).

The new draft will not be the first comment of the IAEA on safety standards; its manual on the safe handling of radioisotopes was published in December, 1958, and its transport regulations will shortly be promulgated. Similarly, in the major nuclear countries and in the Euratom community standards of safety and recommendations for mpl's, etc., have been formulated, and in many instances national legislation has followed. For example, in the United Kingdom the radioactive substances Act received the Royal Assent a year ago and should shortly become operative, and the code on sealed sources is about to come into effect. In the United States a start has been made on the transfer of regulatory power from the Federal Authority to the State Authorities (although this is not proving as simple as might be supposed).

In general terms, then, radiation safety is ceasing to be a matter of opinion laced with expediency, and is becoming one of compulsory precision. One result will be that users will need to define more accurately radiation levels and dosages and it is to the manufacture of health instruments that he will look for his monitoring equipment.

It is against this background that we present this month an analysis of presently marketed health instruments. We do not pretend that this is an exhaustive list although most of the health monitor instrument manufacturers throughout the Western World were circulated and information on their products sought. Some replies were received too late for inclusion and we may at a later stage be able to publish a supplementary list. We regret the omission of full information in some of the entries but we suspect that not all manufacturers appreciate the necessity for defining such characteristics as energy dependence, window thickness, etc., as will now be required under modern regulatory conditions. In the past, manufacturers suffered from a dearth of precise information on what measurements would be desirable but happily this situation is rapidly being resolved. In turn, however, customers' demands will also become specific.

World Digest



View of Hunterston under construction by GEC for the SSEB.

International

An agreement between Euratom and the Brazilian Government for mutual aid and assistance in the development and uses of atomic energy has been signed. Covered are the exchanges of information relating to research and development, health protection, installations and equipment, the exchange of students, technicians, teachers, instructors and collaboration in the field of ore prospecting, installation and equipment construction, the supply of ores, source materials, special fissile materials and radioisotopes, the processing of ores and source materials, and the chemical treatment of fuels. Negotiations are under way for a similar agreement between Euratom and the Argentine.

A draft convention on "Minimum International Standards Regarding Civil Liability for Nuclear Hazards" has been drawn up by the intergovernmental committee which recently met in Vienna under the auspices of the IAEA to revise a draft prepared by IAEA experts in 1959 (see *Nuclear Engineering*, June, 1961, p. 232). The new draft will now be considered by the IAEA board of governors and will probably be submitted to an international diplomatic conference for final approval. The Argentine Government has offered to act as hosts to such a conference.

Permanent Euratom missions for London and Washington are agreed to in principle by the Council of Ministers but before they can be established numerous points of detail have to be settled. It is felt that in view of the increase in activities under the terms of the co-operative agreements between Euratom and the U.K. and U.S.A. the need for such missions is becoming more and more necessary.

A scheme for the Inter-American Nuclear Energy Commission to give financial support to nuclear energy research projects in the fields of biology, chemistry and physics was approved at the Commission's third annual meeting, Washington, D.C., May 9-13. At the same meeting it was urged that member countries should give preferential attention to the financial support of specialized libraries and that there should be more co-operation in the information field.

Studies have been initiated on the possible adaptation of Eurochemic's plant under construction at Mol, Belgium, for reprocessing fuels of higher enrichments than 5%, it was revealed at the recent board meeting. Principal specifications of the plant which is designed initially for handling enrichments of no more than 5% (*Nuclear Engineering*, July, 1960) were approved by the directors and the hope was expressed that construction of the main plant would start in the autumn.

Need for Large-plant Experience

REFERRING to the proposals for Euratom participation in the financing of power reactors, the fourth general report of the commission stresses the need for building and operating large-scale plants in preference to small prototypes if any useful experience is to be gained—a view, incidentally, that seems to be quite different from that expressed at the recent meeting of the consultative committee for research (see panel on page 273). Commenting that the number of power stations under construction was still insufficient for Euratom's needs in terms of experience, the report indicates that the aid proposals, which have yet to be approved by the Council of Ministers, have been drawn up to encourage the building of reactors of various promising types. Altogether nuclear power stations under construction or planned in the community countries will provide by the end of 1965 up to 1 565 MW(e), to which it might be possible to add 300 MW from the BEWAG (Berlin) and KBWP projects, 160 MW from the SELNI proposals and possibly another 150 MW from the PNEM project under discussion for the Netherlands.

Plans for a European ship are being prepared by Norway and will be considered by ENEA in September, according to Mr. Gunner Randers, director of the Institutt fur Atomenergi, Kjeller. The plans are for either a 65 000-ton tanker or smaller ore carrier. Cost of the ship is estimated at £7·5 million with completion in five years.

Euratom's research staff at the end of March, 1961, numbered nearly 1 200 as against 238 a year earlier, states the commission's fourth general report. During 1960 $50 million was set aside for research of which $37·8 million was actually spent.

United Kingdom

Reblading of the turbines at Calder Hall and Chapelcross is taking place in order to meet increased heat output from the reactors brought about by certain modifications. When rebladed each turbine will generate up to 27MW(e), an increase of 6MW, or over 28%, on original expectation.

CEGB's new nuclear research laboratories at Berkeley were opened on May 29 by Lord Fleck, chairman of the Ministry of Power's advisory council on research and development. A description of the centre appears on pages 281-2 of this issue. Coincident with the opening of the laboratories was a conference on the "Properties of Reactor Materials and the Effects of Radiation Damage" held in nearby Berkeley Castle. Over 100 scientists from 15 countries attended. A report on the conference papers appears on page 283.

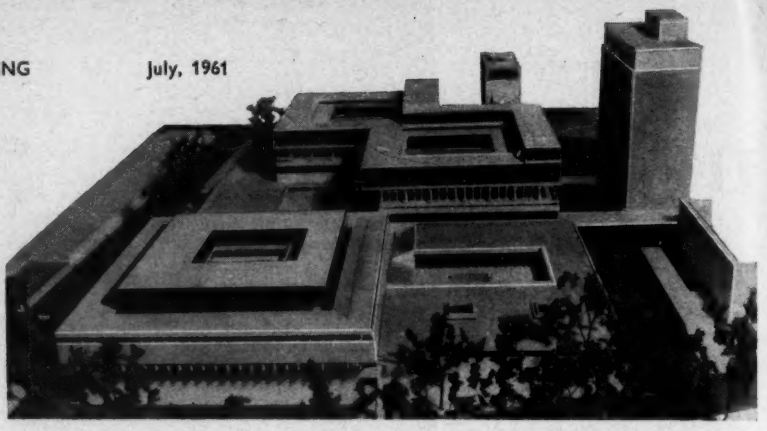
Professor V. S. Emelyanov (*second from left*) with Sir William Cook (*right*) at Hinkley Point. With them are Mr. D. M. Longman, resident site engineer, and Mr. W. H. Sanderson, CEGB project engineer (behind).

In addition to providing for the exchange of information and the holding of joint conferences, the U.S.S.R.-U.K.AEA collaborative agreement signed at the conclusion of Professor Emelyanov's recent visit to Britain ("World Digest," June, 1961) allows for the possible exchange of new instruments and equipment and radioisotopes. Apart from this feature and the fact that the agreement is for five instead of two years it is not unlike the one signed between the U.S. and Russia in 1959. Subjects covered by the AEA agreement are nuclear physics, solid state physics, basic radiation chemistry, inorganic chemistry of elements of importance in nuclear science and technology, research in isotopes and their applications, plasma physics, high energy physics, reactor physics, and experimental fast reactors.

It is understood that AEI are negotiating with Hawker Siddeley for the acquisition of the Jason "know how" and construction rights. If a deal results it will probably mean that universities that have opted for this particular type of reactor will not have to go overseas for it. It is known that one American company without U.K. affiliates is making strong efforts to sell their reactor (of the Argonaut type) here.

After four days the talks in Montreal between an AEA delegation headed by Sir Roger Makins and Canadian officials on the "hidden" contract for 12 000 ton of uranium oxide were adjourned to enable the participants to report back to their governments. As reported in "World Digest" in May, a letter of intent for the purchase of the oxide signed in 1957 is regarded by the Canadians as a firm contract and it is over this the talks are taking place.

A radiation centre planned eventually to house a reactor is being built by Birmingham University at Edgbaston. Construction is scheduled to start next year and among the other facilities it is hoped to include will be gamma ray sources, an electron accelerator, X-ray machines, and a radiochemical laboratory. Whether a reactor will be installed depends on the financial support of the DSIR or other Government sources and it will probably be a year or two before a decision is made. At this stage it has not been settled what sort of reactor would be selected, although it is understood if the university could buy one now they would choose a Triga. The centre is designed to be used by all departments of the science and medical faculties and the reactor also by the physics and metallurgy departments of the Birmingham College of Advanced Technology and possibly other institutions in the Midlands.



While other universities with nuclear ambitions are still gambling on the eventual success of the "Monte Carlo method" of support promised by the Government, Oxford University has brought off a notable coup. On June 1 it announced the allocation of a site for a new science precinct, the major part of which will be concerned with nuclear physics. With commendable reserve, the University accepted a grant of £750 932 from the DSIR for nuclear physics research together with a further sum of £75 000 from the University Grants Committee. A model of the building (above) indicates that the modern school of architecture has triumphed, the design being in the hands of Ove Arup and Partners. Principal item of equipment at the centre will be a particle accelerator of novel design with which Professor Denys Wilkinson proposes to carry out an extended programme of long-term research on nuclear structure. Partly designed by the NIRNS, this machine will comprise an 8–10 MeV vertical Van de Graaff generator coupled to a 12 MeV horizontal tandem Van de Graaff supplied by High Voltage Engineering Corporation of America.

An official history of the development of atomic energy in the United Kingdom is being prepared, Mr. R. A. Butler, Home Secretary, recently disclosed in the House of Commons. The historian who is undertaking the work is Mrs. M. M. Gowing, who for 14 years worked with Sir Keith Hancock, official historian of the 1939-45 war. No prediction has been made as to when Mrs. Gowing's history will be completed.

Nobody interested in nuclear energy marine propulsion can complain about not having their case aired in the House of Commons. The Minister of Transport, Mr. Ernest Marples, is continually being pressed to make a statement on the Government's policy on this subject and recently he had to face on two different occasions separate intense questioning and harassing from four Members. Despite the onslaught the Minister remained obdurate leaving his questioners angry and puzzled.

Argentina

A course in nuclear metallurgy has been arranged by the Argentine Atomic Energy Commission in conjunction with the International Nuclear Energy Committee of the OAS to be held in Buenos Aires from March–December, 1962.

Canada

A Royal Commission to investigate and review the state of Canada's nuclear power policy is urged by Mr. Winnett Boyd, president of Arthur D. Little, of Canada, who recently testified at the inquiry being held by the House of Commons Special Committee on Research into the activities of Eldorado, Atomic Energy of Canada, Ltd., and the National Research Council. An advocate of the HTGR concept, Mr. Boyd suggested to the committee that too much emphasis was being placed by AECL on the heavy water system.

Denmark

By the end of the year Danatom hope to be able to submit to Danish industry up-to-date technical and economic reviews of four reactor systems considered most appropriate for power generation in Denmark under present conditions. One of the reviews will be a revised version of the Beta design study of a 175 MW gas cooled graphite moderated reactor plant (*Nuclear Engineering*, June, 1960). Another will be based on the design study for a 200 MW BWR plant to be sited in Jutland, known as the Gamma project, now nearing completion. The other two will be draft studies of a 150 MW OMR plant and of 150 MW spectral shift control reactor plant.

Canadian Nuclear Association's First Conference

WHILE the heavy water Candu reactor system was being severely criticized before a Canadian House of Commons committee (see separate item), Mr. A. L. Gray, president of Atomic Energy of Canada, at the first annual meeting and conference of the Canadian Nuclear Association, Toronto, May 16-17, was busy reaffirming faith in it. Surveying the country's nuclear power programme he stressed the advantages of the heavy water system particularly for Ontario. He thought the cost of power from the first unit of the Candu type of reactor would be in the 6–7 mill/kWh range, although scientific experts in his company were hoping for less. In another paper presented at the conference, which was attended by over 250 delegates, Mr. G. White, general manager of U.S. General Electric's Atomic Power Equipment Department, San Jose, California, dropped a bombshell by saying that a BWR could be built in Ontario, on the basis of Canadian interest rates and Canadian fuel fabrication costs, to produce power for less than 5 mill/kWh. He admitted, however, that this was just a preliminary estimate and that the use of enriched uranium would make it an unattractive proposition. Mr. Macaulay, Ontario Minister of Energy Resources, told the conference that he thought the Canadian nuclear power programme could be using 400-500 ton of uranium oxide annually by 1970 and about 3 300 ton by 1980 assuming installed capacity by that year to be 6 000 MW(e). He acknowledged that this would by no means solve the marketing problems of the Canadian uranium mines which in 1959 had an annual capacity of 16 000 ton of oxide. The world market for Canadian uranium oxide in 1970 (including the domestic demand) could be about 5 000 ton annually, and more if another contract from the U.K. was obtained and if the non-nuclear uses of uranium became important.

West Germany

A British designed reactor is likely to be selected by the RWE for their proposed 250-300 MW(e) nuclear station at Bertoldsheim, near Neuburg/Donau. The company is currently examining several proposals and it is believed that the most favoured are those for either a BWR or Magnox plant. The feeling is that on account of the U.K.AEA's experience with the Magnox type and because of the strong links one of the English groups tendering for the project has with German industry, the choice will be for the latter.

Out of seven tenders received by the GKSS for the construction of the conventional parts of the OMR propelled ship to be built in conjunction with Interatom the proposals for a freighter have been selected.

Kahl went on load on June 18 at a reduced power level delivering current into the grid for the first time.

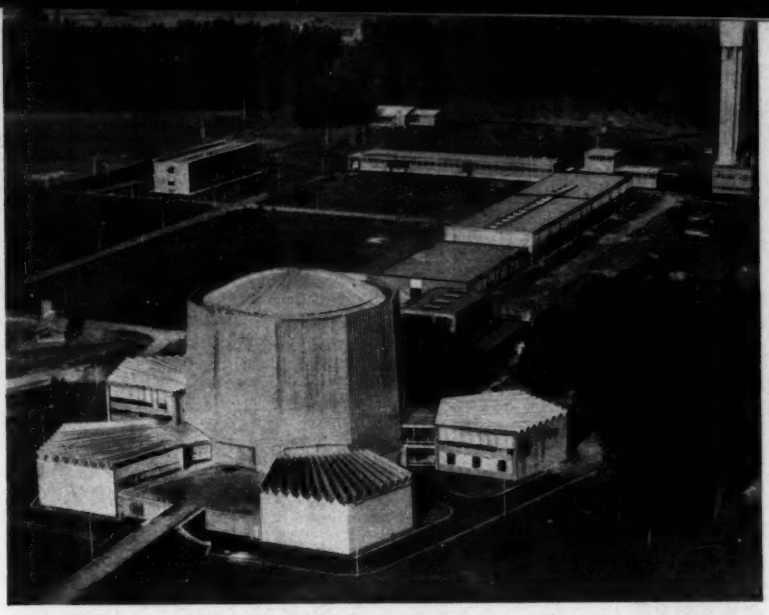
India

Studies are in an advanced stage for a 20 MW(e) heavy water moderated, organic cooled, natural uranium reactor, according to the 1960-61 report of the Department of Atomic Energy, and a project for the construction of such a plant is expected to be shortly started. The department has also been authorized to search for a site for the 150 MW(e) station planned to be built in the Delhi-Punjab-Rajasthan area, although a decision to go ahead with such a station has not yet been taken.

Italy

Expenditure by CNEN during 1961-62 will amount to about £14·5 million, according to estimates recently discussed by the steering committee. Over 40% of the total will be diverted to applied research and just under 20% to basic physics. One of the major projects for which the allocation of funds was approved is the programme for the construction of a prototype organic moderated reactor (PRO) at Bologna. The design study for this, carried out by AGIP Nucleare and SORIN, should be completed within the year, as also should site preparation and part of the civil engineering work.

A contract for about $1 million has been signed between CNEN and Allis-Chalmers for the detailed design of a uranium-thorium fuel reprocessing plant to be built in Southern Italy. Construction of the plant is scheduled to start within a year and when completed it will be possible to demonstrate for the first time the economics of the thorium fuel cycle. The plant will be so designed as to permit the recovery of the uranium-thorium material from the irradiated fuel assemblies of the Elk River reactor plant under construction in Minnesota, U.S.A. It is proposed that the fuel material would be reconstituted, made up into new fuel assemblies at the plant and then returned to the reactor for re-use. Arrangements for the transfer of the fuel material, which are being studied, would involve the close co-operation of the U.S.AEC, Euratom and CNEN.



Operational power level of Avogadro-RSI, Sorin's AMF pool type reactor at the Saluggia research centre, was recently raised from 1 MW to 2 MW. Eventually the power level will be raised to a maximum of 5 MW. The reactor first went critical in September, 1959.

Japan

Under a 20-year nuclear power programme Japan plans to have her first nuclear propelled ship constructed and in operation by 1968-70, after which it is hoped to build a fleet of nuclear vessels. The first one will utilize a light water reactor and to further studies on this reactor type a swimming pool reactor supplied by General Electric, of America, is being installed at Tokai Mura (see paragraph below). Although the ship research and design effort during the first part of the 20-year programme will be concentrated on the first vessel studies will also be made of the potentialities of nuclear submarine merchant vessels, the development of OMR and gas-cooled propulsion units, and the use of nuclear superheating.

A light water reactor is to be supplied to the Japan Atomic Energy Research Institute, Tokai Mura, by General Electric, America, through its subsidiary, General Electric Japan. To be known as the Light Water Critical Assembly (LWCA), the reactor will be designed to operate at powers up to 200 W(th) and will be used for providing nuclear data for the design and evaluation of light water moderated and cooled reactor cores. Scheduled completion date is July, 1962.

Some of the plates for the reactor pressure vessel of the 150 MW Tokai Mura plant are to be supplied by Japanese steelmakers in order to prevent any disruption in the construction schedule. At the works of the British manufacturer with whom the contract for plate was placed cracks were observed on ageing plate made by a new process. Part of the shipment to Japan contained plate made by this process and had to be scrapped. This portion of the plate will be replaced by the Japanese material. Meanwhile back in Britain the new process has been abandoned and the rest of the plate for the reactor vessel will be treated according to established techniques.

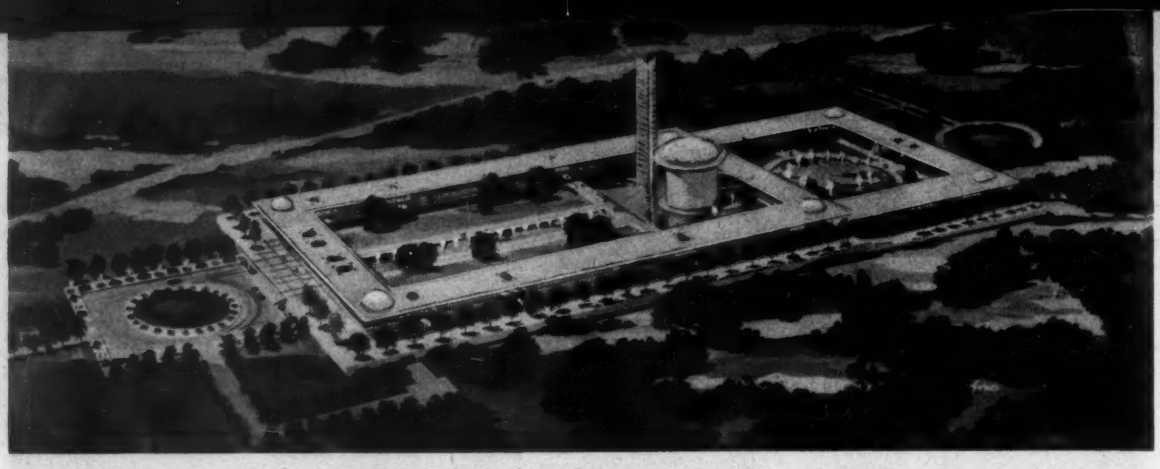
Norway

Nora, the heavy water zero energy reactor at Kjeller, was put into operation on June 9. Built by the Institutt fur Atomenergi, with Noratom as the main contractors, the reactor took two years to build and cost in the region of N.Kr. 6 million (about £300 000), a third of this sum being supplied by the U.S.A. As reported in "World Digest" in March the reactor is to be operated by an international team.

A uranium reprocessing pilot plant has been put into operation at Kjeller under the auspices of the Institutt fur Atomenergi. It will be used for testing various reprocessing methods and flowsheets and will supplement experience gained by Norway and Netherlands, who run the Institutt, from their participation in the Eurochemic project.

French Against Euratom Power Aid

PROPOSALS for Euratom participation in the financing of power stations, referred to in last month's "World Digest," have been discussed by the consultative committee for research and redrafted for consideration by the Council of Ministers at a meeting in early July. The proposals were supported by five of the national delegations to the committee, only the French having serious reservations, except, it must be added, on the SENA project. They are decidedly in favour of Euratom support for this project. Other representatives consider that prototype reactors developed in Europe were more deserving of Euratom aid and urged that the programme should not be limited to large power reactors. Particular emphasis to this point was given by the Germans and Dutch. It is proposed that aid in the first instance should amount to $7 million to SENN, $8 million to SENA and $4 million to SIMEA, and that total aid paid out under the scheme as a whole should not exceed $40 million.



Artist's impression of the $8 million Institute of Nuclear Science and Engineering to be built at Islamabad, the new capital city of Pakistan. When completed it will contain 16 science, engineering and administrative buildings. Site preparation has started and one of the first buildings to be completed will house a pool-type reactor supplied by AMF who are also to design and construct the reactor building and supporting laboratories. A West German consortium formed by Unde, Lurgi Nukem and Leybold-Hockuakuum-Anlagen will design and construct the Institute's fuel processing and chemical engineering facilities. Announcement of plans for the Institute coincided with the news of a $550 million aid plan for Pakistan from six countries and two international organizations.

Sweden

Westinghouse Electric, New York, in collaboration with the Johnson Company, Stockholm, and the Bechtel Corporation, San Fransisco, are to carry out for Atomenergi an eight-month feasibility study on the 250 MW homogenized (i.e., not pressure tube) pressurized heavy water reactor (HPHWR) concept, in which Atomenergi have been interested for some time.

Switzerland

The Government is to make Sw.Fr.50 million available for the 30 MW(th) heavy water moderated, pressure tube reactor plant to be built at Lucens in West Switzerland by Compagnie Nationale, the group made up of Energie Nucleaire, Suisatom and Thermatom (" World Digest," January, 1961). Sums over this amount (the total construction costs are put at Sw.Fr.70 million—about £5·8 million) will be met by the group.

U.S.S.R.

A fast neutron pulse reactor has been put into operation at the Joint Nuclear Research Institute, Dubna, Moscow. It is designed to yield bursts of fast neutrons at every few tens of microseconds and it will provide the experimental basis of the neutron physics laboratory recently established at the Institute. A reactor that is designed to produce similar results is now under construction at Oak Ridge, the Fast Burst Reactor (" World Digest," February, 1961), the basis of which has been the series of sub-critical assemblies known under the generic name of Godiva (so called because the core is unshielded).

Lenin, **the nuclear powered icebreaker,** is now lying in the Murmansk roadstead, made ready for her second Arctic season. The reactor plant, which functioned so well during the last season, together with the conventional parts have been thoroughly overhauled and the hull checked and found to be in good condition.

Yugoslavia

A small- or medium-sized demonstration nuclear power plant might be built by the Federal Nuclear Energy Commission in conjunction with the IAEA. Preliminary technical, legal and financial studies have been agreed upon. Mr. Sterling Cole, IAEA director, considers such a project would be " of special interest to the less-developed countries."

U.S.A.

Reductions of 20-34% have been made by the AEC in the price of enriched uranium, the amount of reduction depending on the degree of enrichment. The new base charge for 90% enriched fuel, for example, is now $13.65/g compared with $17.07/g before, while 1% enriched uranium costs $4.99/g compared with $7.58. The cost of depleted uranium in the form of uranium hexafluoride has also been reduced, the cut amounting to 63%. While the reductions have been welcomed by industry there is a general feeling that they will later be offset by readjustments made in fuel reprocessing costs.

Raising of the Yankee plant's operational power level from 110 to 134 MW(e) has been approved by the Advisory Committee on Reactor Safeguards, provided certain modifications to the reactor are carried out. One aspect of safe operation of this reactor that had not been previously resolved by the ACRS related to testing the reactor for the effects of plutonium build-up at about 2 000 h intervals. Methods of procedure adopted for this have been approved and the committee has noted that there were in fact no detectable effects of plutonium build-up during the first 2 000 h period. The committee recommend, however, that in-core monitoring is continued at least with the first core.

Organizations using process steam have been invited by the AEC to express interest in participating in a demonstration low temperature process heat project. If the response indicates that an acceptable proposal is likely the AEC will invite detailed proposals. The AEC would construct and own the reactor, which would have to be based on current technology, have an output capacity of between 30-45 MW(th) and operate at pressures from 15 to 200 psi. It is hoped that operation of the reactor could start in the 1964-65 winter. At one time the AEC were to build a 40 MW(th) process reactor for use as a saline water conversion unit by the Department of the Interior. The plans were laid aside when agreement could not be reached as to a suitable site—the first suggested site was opposed by the Advisory Committee on Reactor Safeguards and the second one did not meet with the requirements of the Department.

While the Air Force's first reactor plant was being flown out to its remote site in the Wyoming mountains, tenders were being invited for another portable reactor for the Antarctic. The AEC, who are currently procuring a reactor for the Navy for operation at McMurdo Sound in 1962, now want one for the Byrd Station, where certain studies are being carried out by the National Science Foundation. It is specified to be either a PWR or BWR plant with an output of 1 MW(e) and 1·5 million Btu steam, the latter to be used for operating a snow melting unit. Operation date is given as March, 1964, and designation of the reactor will be PL-3. The Air Force plant, PM-1, is capable of producing 1 MW of electric power and 2 MW of heat.

Two companies out of seven have been selected by the joint AEC-NASA nuclear propulsion office to undertake the first phase in the programme for the development of a nuclear rocket engine (" World Digest," June, 1961). They are Aerojet-General and Westinghouse Electric and they will carry out a six-month design study of the engine, assist AEC scientists working on nuclear propulsion at Los Alamos and prepare a long-term development programme.

Tory II A-1, the first of the Project Pluto reactors to go critical (" World Digest," April, 1961), was recently successfully operated at a pre-planned power range of 40 MW(th) for about 45s at temperatures in excess of 2 000°F. Project Pluto is the programme for the development of nuclear power for ramjet propulsion.

The AEC published on June 11 the final report of the Board of Investigation set up after the SL-1 accident. Although the Board say they could not assign the cause or the responsibility for the explosion to any known or unknown act or condition preceding the incident, it is their judgment that " before the incident occurred, the condition of the reactor core and the reactor control system had deteriorated to such an extent that a prudent operator would not have allowed operation of the reactor to continue without a thorough analysis and review, and subsequent appropriate corrective action, with respect to the possible consequences or hazards resulting from the known deficiencies. We believe that such review and action should have resulted in modifications to design, administration and operation sufficient to ensure that there was no potential hazard greater than contemplated in the original hazards report and review, before reactor operation was resumed.

AEC-PRDC win their case

FOR the AEC and nuclear power industry the suspense is at last over—the AEC and PRDC have won their Supreme Court appeal in the Enrico Fermi reactor case. By seven votes to two the court has rejected the submission of the unions, upheld by a lower court, that a construction permit should be granted on exactly the same safety evaluation as that required for an operation permit. Speaking for the majority vote Justice William Brennan said the commission was acting within the authority granted to it by Congress and that it could not be assumed that the AEC would exceed its powers or that the many safeguards carried out to protect the public interest would not be fully effective. Speaking for the minority Justices William Douglas and Hugo Black said that the AEC and the court were taking a "light-headed approach to the most awesome, the most deadly, the most dangerous process that man has ever conceived." The findings of the court, which considered the appeal on April 26-27, were made public on June 12, so bringing to an end a twelve-month case which has been followed with acute interest throughout the world (*Nuclear Engineering*, August, September, 1960; January, March and June, 1961). As pointed out by Justice Brennan, however, it does not necessarily mean it is the last we will hear of the matter. An operating licence has yet to be issued and there is a likelihood that if granted it will be opposed by the unions.

Current methods of licensing procedures and organization came under criticism during the recent public hearings on "Radiation Safety and Regulation" held by the Joint Committee on Atomic Energy at which proposals for improving them were discussed. Chief of these proposals is a plan put forward by the University of Michigan for the establishment of a separate agency for handling the AEC's regulatory functions. The idea was published in March with studies of the problem made by the AEC and JCAE and on which the AEC has already acted. Certain organizational changes have been made including the creation of a director of regulation with direct responsibility to the Commission. These changes will not prejudice fair consideration of other proposals.

Dresden is back on load at an operational level of 150 MW(e).

Although not requested by the Navy a second nuclear-powered frigate similar to the *Bainbridge*, launched in April ("World Digest," June) is to be built. Authorization of the project was given by Congress after hearing the views of Admiral Rickover, and they also approved the construction of 10 Polaris and three attack submarines.

A new metallurgical development and fuel fabrication centre is to be built by General Atomics next to the John Jay Hopkins Laboratory for Pure and Applied Science, San Diego. It will cover 52 000 ft², cost about $2 million and should be completed by next year.

While approving the operation of the Piqua plant at power levels of 45·5 MW(th) the Advisory Committee on Reactor Safeguards recommend that at each partial fuel reloading of the reactor (approximately at four to six monthly intervals of power operation) an inspection be made of typical sample portions of the remaining fuel elements. Reports based on this inspection should then be sent to the AEC Division of Licensing and Regulation.

A new potential operator for the 50 MW ICBWR that was originally to be built in Haskell Canyon, California, has been found by the AEC. It is the Dairyland Co-operative, of La Crosse, Wisconsin. The plant, which will be designated the La Crosse Boiling Water Reactor, will incorporate internal steam separation and be designed and constructed by Allis-Chalmers. They will also supply the first core, train operating staff and perform pre-acceptance station tests, all for about $10 800 000. Dairyland will provide the turbogenerator and a site, near Genoa, Wisconsin, will operate the reactor for the AEC for 10 years and buy the steam produced by it. The site, having previously been found suitable for an OMR project, is concluded by the ARCS and AEC to be suitable for the ICBWR.

Proposed conversion of the plutonium production reactor under construction at Hanford for power generation ("World Digest," May) has met with some opposition. At the May-June meetings of the Joint Committee on Atomic Energy it was argued that the project was not economically feasible and that it was not a proper function of the federal government to build and operate thermal plants for the production of power for sale to the public. The plan is for installation of 700 MW of generating plant at a cost of $95 million.

Correspondence

Electro-slag Welding

Sir,

We note with regret a substantial omission from your Welding Equipment Survey, published in the May issue of *Nuclear Engineering*. Apart from a reference to OK Electrodes under Lerch Machine Tools, "ESAB," which is the oldest and largest electrode manufacturing organization in the world, is not referred to.

We are proud of our electro-slag machinery which is manufactured under licence from the Paton Institute of Russia who were the inventors of the process. Two of our machines will shortly go into production with important companies in Great Britain.

We took possession, in the early part of this year, of new premises at Birmingham for the sole purpose of demonstrating and servicing automatic machinery.

R. EVAN COOK,
Sales Manager, ESAB, Ltd.

Sir,

I have read with interest your Editorial in the May issue of *Nuclear Engineering*, but feel bound to comment on the paragraph dealing with electro-slag welding.

As you are doubtless aware, there are now several electro-slag machines operating in the U.K., and the many papers published on the mechanical properties obtained from electro-slag welds have at no time given any cause for concern regarding the ductility of welds made by this process. For example, the following results were obtained from electro-slag welds in 4½ in thick plate made at these works with our Russian-built machine:—

Steel	Tensile Strength t.s.i.	Yield Strength t.s.i.	Elongation on 2 in.	Reduction of Area
B.S.1501-161 Grade B	32·8	22·0	32%	64%

These results are average, and similar figures have been quoted by other investigators.

The application of a post weld heat-treatment (i.e., full normalizing) is carried out to improve the Charpy Vee-notch impact strength, but it is quite misleading to imply that this is something new. It has been known since the introduction of the process, some 10 years ago, that in order to meet the stringent impact requirements laid down for pressure vessels of severe duty a full normalizing heat-treatment was necessary. When this is carried out the low temperature impact properties of the welds are at least as good as those of the unwelded plate.

I am quite confident that your somewhat pessimistic view regarding the application of electro-slag welding to nuclear engineering will shortly be dispelled.

Thornaby-on-Tees.

M. H. HIPKINS, Esq.,
Chief Metallurgist,
Head Wrightson and Co., Ltd.

Reactivity Fluctuations

Sir,

I would like to draw your attention to two small errors and an oversight in the above article published in your May issue.

Referring to Fig. 7 the linear dynamic elements should be characterized by $G^1(Jw)$ and $G^2(Jw)$.

The third paragraph under the heading of Conclusions should terminate with the word "processes."

Finally, reference No. 4 relating to reactor pathology should have been given as:—

4. Smets, H. B., and Gystopoulos, E. P., "The application of Topological Methods to the Kinetics of Homogenous Reactors," *Nuclear Science and Engineering*, Vol. 6, pp. 341-349 (1959).

L. G. KEMENY,
Queen Mary College.

Peach Bottom

Sir,—In case our good neighbours to the south (General Atomic) haven't already sent their comments on your June issue, here's ours: the Peach Bottom HTGR (photo on page 228) is not being developed by Atomics International.

RICHARD E. JESPERSEN,
Atomics International.

[*Ed.—We trust that this example of mental aberration was recognized as such. A summary of reports on General Atomic's HTGC projects (supplemented by Dr. Fortescue's paper to the Sixth Nuclear Congress in Rome) appears on page 307 and includes details of the Peach Bottom plant.*]

Belgium's Novel Research Reactor—BR-2

BR-2, one of the three reactors installed at the Centre d'Etude de l'Energie Nucleaire, Mol, Belgium, is all but ready for the start of operational testing and as it contains some novel features it is worth while to recall these. A detailed description of the reactor design was presented at the 1958 Geneva Conference* and although in principle the design is still the same, in detail some changes have been made, notably in the fuel elements and in the internal arrangements of the reactor vessel.

It is a materials and engineering test reactor designed to yield easily accessible high neutron fluxes—at a power level of 50 MW(th) the epithermal neutron flux is in fact designed to be as high as $2{\cdot}4\times10^{15}$ n/cm²s and the average thermal neutron flux $6{\cdot}3\times10^{14}$ n/cm²s. Fuel is 90% enriched uranium and it is moderated and reflected by light water and beryllium, and cooled by light water.

There are 79 core lattice positions in the reactor and to each one there is direct, independent access through the reactor vessel. As it is necessary to keep the core compact in order to maintain a negative coefficient and to have a minimum critical size mass—it is, in fact 44·3 in in diameter and 36 in deep—the core access channels are arranged in such a way that they form the generating lines of revolution hyperboloids whose symmetry coincides with the core midplane. That is, the channels are bundled together in the central core region but have their ends splayed out. In this way sufficient room is ensured between the channels for making adequate seals where they pierce the reactor vessel and for giving easy access to each channel. Such an arrangement accounts for the most striking external feature of the reactor, its hour-glass or diabolo shape.

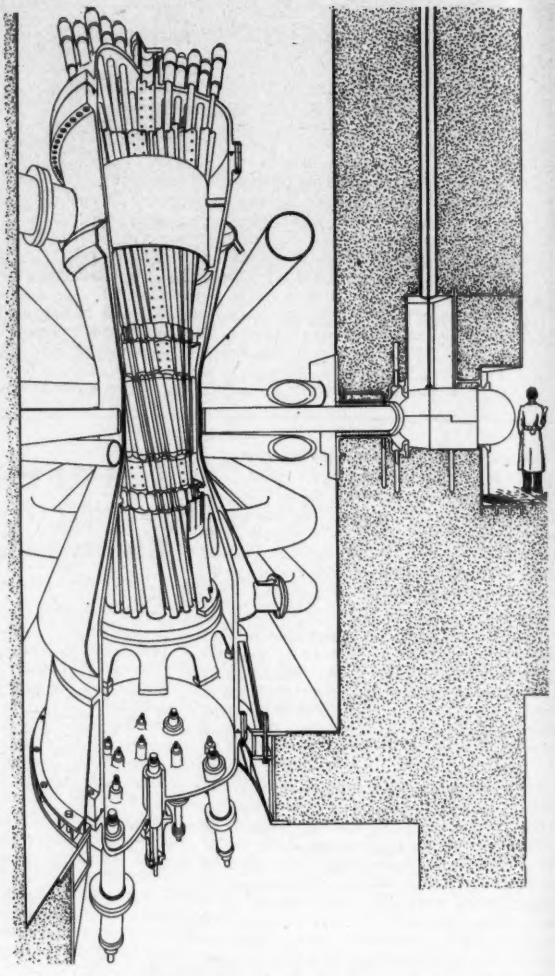


Fig. 1.—Isometric drawing of the BR-2 reactor vessel showing arrangement of the fuel channel assemblies and the beam tubes.

TABLE 1—Research Facilities

Designation	No.	Useful dimensions	Neutron flux (n/cm²s)
Horizontal beam holes reaching reactor vessel	3	12 in	th. max. 6×10^{13} f. max. 6×10^{13}
Horizontal through holes tangential to vessel	5	12 in	th. max. 6×10^{13} f. max. 6×10^{13}
" In pile " positions ..	1	8 in	th. max. $6{\cdot}2\times10^{14}$ f. max. $2{\cdot}4\times10^{15}$
	4	8 in	th. max. $2{\cdot}8\times10^{14}$ f. max. $9{\cdot}4\times10^{14}$
	10	2 in	th. max. $2{\cdot}8\times10^{14}$ f. max. $9{\cdot}4\times10^{14}$
	max. 13	3·5 in	th. max. $2{\cdot}8\times10^{14}$ f. max. $9{\cdot}4\times10^{14}$
	max. 25	3·5 in	th. max. $2{\cdot}8\times10^{14}$ f. max. $9{\cdot}4\times10^{14}$
Hydraulic rabbits.. ..	4–6	1 in	th. max. $2{\cdot}8\times10^{14}$ f. max. $9{\cdot}4\times10^{14}$
Fast irradiation (in fuel elements)	10–15	1·3–3 in	th. max. $6{\cdot}2\times10^{14}$ f. max. $2{\cdot}4\times10^{15}$
Pool irradiation facility ..	1	16×36 ft 250 ft deep	th. max. 6×10^{13} f. max. 6×10^{13}
Core mock-up facility ..	1	12×8 ft 26 ft deep	
Gamma irradiation facility	1	12×8 ft 23 ft deep	

The 79 channels are in three sizes—64 of them are 3·5 in i.d. usable for fuel, control and experiments; five are 8 in i.d. usable for experiments but which, with modification, can also be used for fuel and control rods; and 10 are of 2 in i.d. for, for instance, rabbit experiments. Provision is made for through loops to be used in the 8 in channels and in 13 of the 3·5 in channels. Experiments can also be placed inside the fuel elements, which are made up of six concentric tubes of a 20% w/o U-Al alloy clad with Al, diameter of the central aperture being 1·3 in. If necessary, the inner tubes can be removed for the insertion of larger experiments. Similar fuel elements are used elsewhere, notably in the Soviet RPT.

The shape of the reactor enables beam tubes to be placed very close to the core and four 12 in dia. tangential tubes and five 12 in dia. radial tubes will be installed, making available maximum thermal neutron fluxes of $0{\cdot}6\times10^{14}$ n/cm²s. If required, the beam tubes can be replaced by large experimental equipment. The reactor is installed at one end of a 51 ft deep, 49 ft long by 16 ft wide open tank of demineralized water leaving plenty of

* " BR-2—the Belgian material and engineering reactor," by H. Dophie and J. Planquart. A summary appeared in *Nuclear Engineering*, September, 1958.

BR-2 : Principal Parameters

TYPE
Thermal, heterogeneous, light water and beryllium moderated and cooled, light water reflected.

OUTPUT
Thermal rating 50 MW.

FUEL
90% enriched uranium alloyed with 75–80% Al, in Al sandwich; average fuel rating: 10 MW/kg(U).

CLADDING
0·015 in Al sandwich plate.

FUEL ELEMENTS
6 concentric tubes of sandwich plate; overall dia. 3·315 in; i.d. of central tube 1·3 in.
Active length 30 in; total length 36 in.
Gap between tubes 0·117 in; 30% burnup.

CORE
Moderator: light water and beryllium.
Reflector: light water and beryllium.
Dimensions: 43·3 in dia., 36 in high.
No. of channels: 64—3·5 in i.d.
10—2 in i.d.
5—8 in i.d.
Lattice: hexagonal, 3·893 in pitch.

PRESSURE VESSEL
Hour-glass shape of Al with s.s. covers; overall height, 28 ft; i.d. at widest section 7 ft and at waist 3·65 ft.
Design working pressure 210 psi.

COOLANT CIRCUITS
Light water.
Primary circuit:

Inlet pressure	174 psi.
Inlet temperature	40°C.
Outlet pressure	142 psi.
Outlet temperature	47°C.
Rate of circulation downward	27 500 U.S. gal/min.

Secondary pool circuit:

Mean temperature	35°C.
Rate of flow	4 000 U.S. gal/min.

HEAT EXCHANGERS
Primary circuit:
3 banks, tube and shell type, primary circuit in tube.
Secondary circuit:
4 air-cooled towers.

CONTROL
10 to 15 shim safety rods.
Active section: 1·6 in dia.:
Upper part 36 in Cd in Al cladding;
Lower part 36 in Be.
1 regulating rod.
Active section: 1·6 in dia.:
Upper part 36 in Cd in Al cladding;
Lower part 36 in Al.
Worth of shim safety rods:
Each about 4% $\frac{\Delta k}{k}$.
Total: at least 40% $\frac{\Delta k}{k}$.
Worth of regulating rod:
0·5% $\frac{\Delta k}{k}$ for a stroke of 18 in.
Speed of safety rods: 4 in/s.
Speed of regulating rod: 23·5 in/s.

SHIELDING
Sides: H_2O, minimum 76·5 in; barytes concrete 8·5 ft.
Top: 22 ft H_2O.

CONTAINMENT
0·75 in steel cylinder, 104 ft i.d., 130 ft high, cylindrical part-lined with 2 ft concrete.
Leakage rate: 1·5% atm/d.

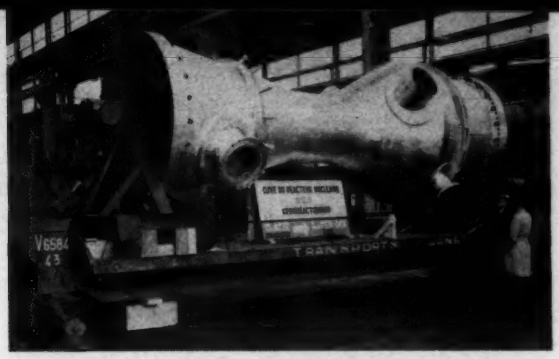


Fig. 2.—The aluminium section of the pressure vessel.

room to do this, adding yet another feature to the reactor's versatility.

At the other end of this tank, there is the cover to a 36 ft long chute for transferring irradiated fuel elements and whole test rigs to a high activity dismantling cell. Two shallow annexes to the tank also at this end provide accommodation for a mock-up of the BR-2 core and a gamma irradiation facility.

Euratom to Use Reactor

The reactor and ancillary equipment are all placed inside a 130 ft high, 104 ft dia. domed containment vessel fabricated from 0·75 in steel and designed to withstand pressures of up to 13·5 psi above atmospheric pressure. Everything is laid out within this vessel to provide the maximum of space for experimental work and there is plenty of room for equipment additional to that already planned. When the reactor is ready for normal functioning Euratom will share in its operation and use.

Construction of the reactor, designed by CEN with NDA of White Plains, U.S.A., and BEN of Brussels in association with Sofina and Sovetreaux, has been the sole responsibility of CEN and, with the exception of the first fuel elements, the beryllium pieces and some of the coolant pipework, the components have been fabricated and supplied by Belgian industry. Work on site started in September, 1957, and delays have been caused in the original construction schedule as is usual when unfamiliar manufacturing techniques are called for. Cost of the project is now likely to be in the region of £18 million.

Complex has been the designing and machining of the access channels; 78 out of the 79 of these are inclined from the vertical at angles varying from 3° 32′ to 10° 42′ (the central 8 in dia. one is upright) and they all have to fit properly into the reactor vessel and with each other without impeding coolant flow. Access to the channels is provided by 79 ducts welded on to the top of the reactor vessel, and each channel is connected to its duct by means of a double-screw coupling which is designed to provide airtight sealing. The channels are supported inside the reactor vessel by means of extension rods that rest on a grid at the bottom of the vessel.

The length of each channel, including the support extension, is 22·1 ft, and except for a 36 in long beryllium section the channel is fabricated in stainless steel. These beryllium sections are so positioned as to fall in the "waist" of the diabolo or hour-glass convolution of the pressure vessel and it is convenient to take them as a starting point for a description of the complete channel construction. The beryllium sections are themselves hexagonal blocks centrally pierced with 8 in, 3·3 in and 1·97 in holes and are machined on the outside so as to fit with each other, forming a core matrix 44·3 in in diameter and 36 in deep.

Immediately above and below the beryllium sections are two 25 in long stainless steel cylinders. These are pierced with holes to facilitate coolant flow into the channel through the top cylinder and out through the bottom one.

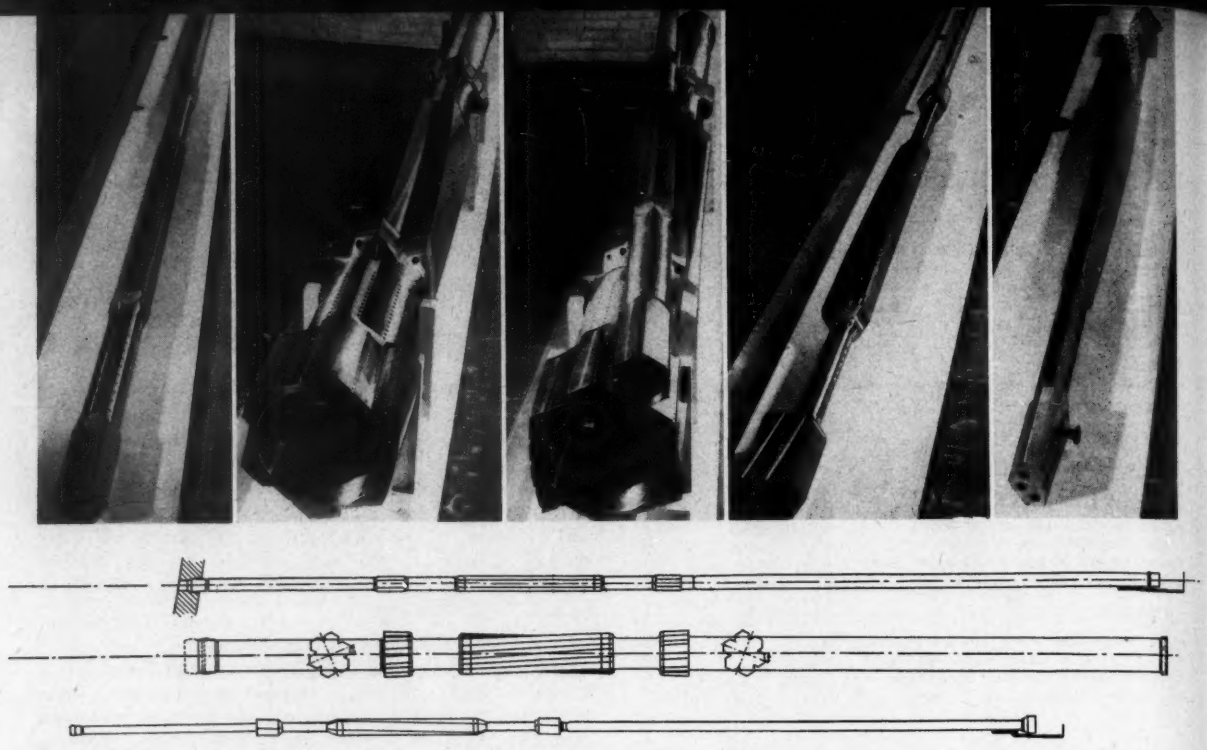


Fig. 3.—The fuel channel assemblies. In the half-tone are shown (from left to right) a 3·5 in i.d. channel; an 8 in i.d. channel; an 8 in i.d. channel with a 3 in i.d. one to show how they fit together; a 2 in i.d. channel and one of the peripheral assemblies for rabbit experiments. The line drawings are (from top to bottom) of 3·5 in, 8 in, and 2 in channels.

At the far ends of the steel cylinders are stainless steel protruding guide pieces or spacers. These are about 50 in deep and like the beryllium sections are machined to fit into each other and at the same time are grooved to allow free coolant flow. Their function is to keep the channels properly spaced within the hyperbolic convolution and they replace the top and bottom reactor grids proposed in the original design. Peripheral restraint which would have been provided by these grids, is now given by encircling reinforcing bands fabricated on to the inside wall of the reactor vessel.

The channels above the top channel spacers are made up of plain stainless steel cylinders which fit into the ducts in the top of the reactor vessel. Below the bottom spacers are the stainless steel support tubes. These are 52 in long and rest on a 70 in dia. steel platform towards the bottom of the reactor vessel. This platform is pierced so as to facilitate coolant flow and provision is also made for extending the 8 in and 13 of the 3·5 in channels so as to pierce the bottom of the reactor vessel for through loop experiments.

The hexagonal beryllium sections do not absolutely fit at the periphery of the core matrix and the spaces formed are filled by means of specially machined assemblies, 10 of which contain the 2 in channels.

The 28 ft high reactor vessel has a main body of aluminium with top and bottom domes of stainless steel.

TABLE 2—The Channel Angles

Diameter	No.	Angle to vertical
8 in	1	0°
3·5 in	6	3° 32′
3·5 in	6	4° 5′
3·5 in	12	5° 24′
3·5 in	6	6° 7′
3·5 in	2	7° 3′
3·5 in	8	7° 20′
3·5 in	6	8° 20′
3·5 in	4	8° 51′
8 in	4	8° 51′
3·5 in	8	9° 18′
3·5 in	6	10° 8′
2 in	2	10° 31′
2 in	8	10° 42′

The aluminium body 23 ft high, is made up of four sections and two flange pieces. The top section is a truncated cone, 8·9 ft high and with a top side of 7 ft and lower i.d. of 3·6 ft. Next comes the central "waist" piece which is 2·8 ft high, 3·6 ft i.d., a lower truncated cone, 6 ft high and with diameters similar to the top cone. The last section is

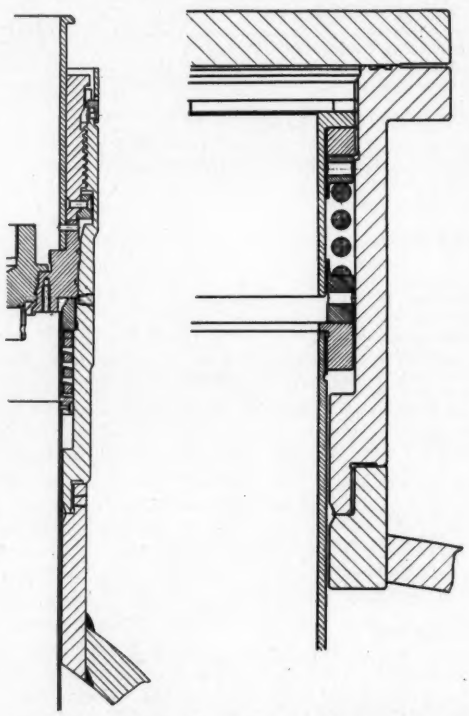


Fig. 5.—Detailed section through one side of 3·5 in and 8 in ducts in the top pressure vessel dome showing method of connection to the fuel channels.

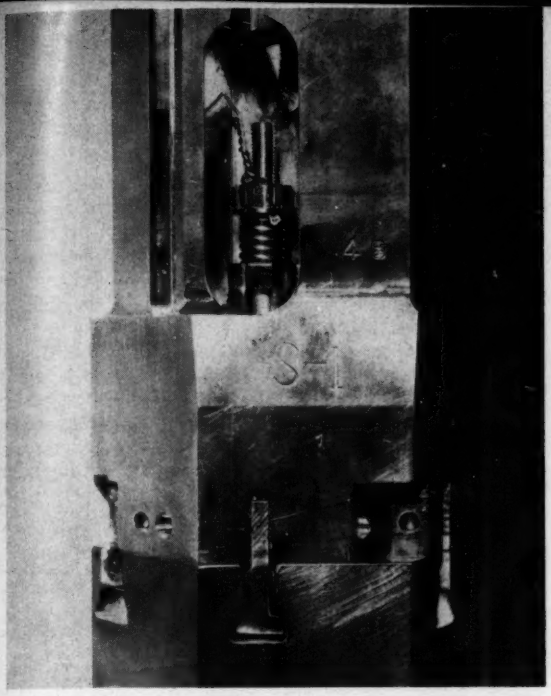


Fig. 4.—View of a peripheral channel assembly showing the means of connecting the beryllium section to the stainless steel parts.

a cylinder a little longer than the middle section and with a 7 ft-i.d. The middle section is fabricated from 0·8 in thick plate and the total weight of the aluminium including the flanges is about 8·5 ton.

The flanges, 13 in in height, provide means for bolting the stainless steel domes to the aluminium section and air-tight closure is assured by the use of asbestos-filled aluminium gaskets.

The top dome, 34½ in high and weighing about 3 ton, contains 79 ducted apertures for the access channels which are connected to the ducts by means of a double screw coupling to effect air-tight seals. Air and water lines are available to check for leaks.

The lower dome, which is also 34½ in high, contains provision for apertures which can be used if any of the 8 in or 13 3·5 in access channels are extended for through loop experiments. The vessel is mounted by means of a 2·4 ft high support skirt inside an opening in the bottom of the tank thus facilitating the use of through loop experiments. The skirt, which is welded on to the reactor vessel at the top of the lower aluminium cylindrical section, is attached to the bottom of the pool by means of leak-tight joints. Just in case these should fail the experimental rooms immediately below the tank are fitted with flood gates.

There are two coolant circuits to the reactor. According to calculated data for normal full power operation, the primary circuit would enter the two ducts in the top aluminium section at a temperature of about 40°C and pressure of about 174 psi and leave via the lower conical section at a temperature of about 47°C and pressure of about 142 psi. Flow rate in this case would be about 27 500 U.S. gal/min.

The secondary circuit serves the pool and at the same time is used to cool the outer wall of the reactor vessel which for this purpose is surrounded by an aluminium shroud, 16 ft high (see Fig. 7). At the mid plane of the reactor, temperature of the coolant will be about 35°C and flow rate will be about 1 850 U.S. gal/min. Outlet pipes for the primary circuit traverse the length of the reactor tank thus losing some of their heat to the tank water. The primary circuit is cooled by a heat exchanger

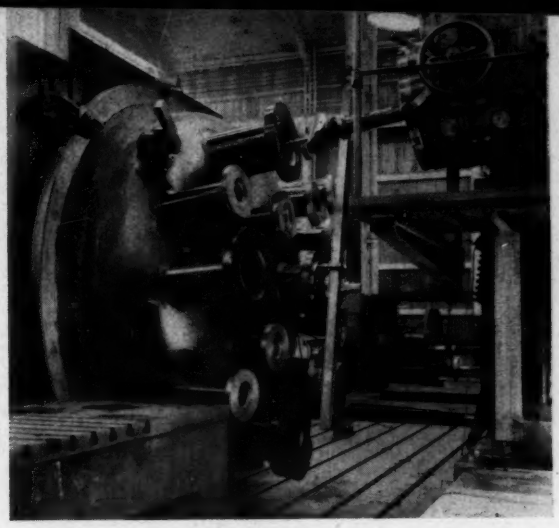


Fig. 6.—Machining of the bottom pressure vessel dome.

served by the secondary circuit and circulation is maintained by four pumps each of 9 300 U.S. gal/min capacity. In an emergency, such as when a rupture occurred in the circuit outside the tank, the circuit is confined to the tank and circulation is maintained by means of convection in the tank water. The primary circuit also contains two pumps of 3 500 U.S. gal/min capacity for use in maintaining circulation during a shutdown and the circuit is also served by demineralization, degasser and pressurization plants.

The secondary circuit loses heat in an air cooling tower and circulation is maintained by four pumps each with a capacity of 8 800 U.S. gal/min. A third coolant system serves experiments and is provided with two pumps.

It is calculated that criticality will be achieved with a fuel loading of about 1·5 kg of U^{235} and for typical core loadings at 50 MW(th) 4 kg are anticipated. Loadings will be made up of elements each containing 244 g U^{235} enriched to 90%, alloyed with 75/80% weight of aluminium and sandwiched between 0·015 in thick aluminium. Each element comprises six 38 in long concentric tubes made up from this sandwich and with an overall diameter of 3 in. The tubes are held together by three radial spacers, the

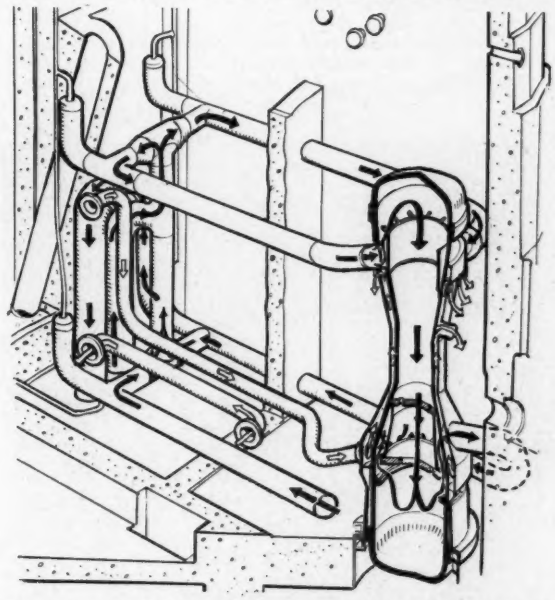


Fig. 7.—Simplified drawing showing the coolant circuits. Black arrows denote primary flow and open arrows secondary circuit.

Fig. 8.—Artist's impression of cross section of fuel element to be used in BR-2.

gap between the tubes being 0·11 in. Active length of the elements is 30 in.

The use of spacers is a divergence from the method of assembly used in the elements that have been tested in the critical assembly BRO-2. In these, the three sectors that make up each tube are lipped back and crown welded.

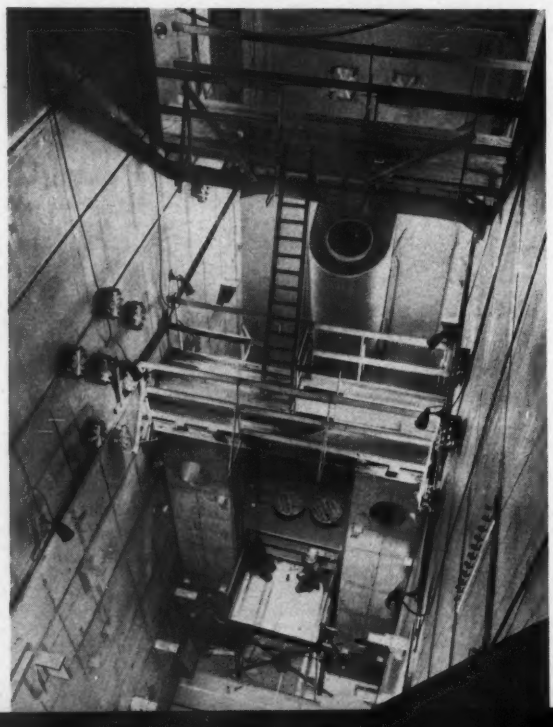
Fuel is loaded and unloaded into the reactor by means of a simple manipulator mounted on a shielded trolley that runs across the top of the reactor tank. From experience gained with the critical assembly, there is no difficulty in loading elements at the various angles.

Control is to be effected through the use of about 15 shim rods with diameters of 2½ in and of one regulating rod. Upper parts are in aluminium clad cadmium, the lower part beryllium.

The total reactivity worth of the control rods might be as high as 40%, corresponding to the calculated maximum built in reactivity balance of 20%.

Channels not utilized with either fuel, control rods or experiments can be plugged with beryllium cylinders of 3·3 in dia. surrounding a centre beryllium rod of 1·35 in dia. The centre piece can in fact be removed for experiments to be inserted.

Fig. 9.—The reactor tank before erection of reactor had started. In the second compartment is the chute for transferring irradiated fuel and whole test rigs to a high activity dismantling cell.



Before any experiments are carried out in BR-2 relevant core configurations will be tried out in the critical assembly BRO-2 which is a replica of the core portion of the reactor proper. Several configurations have already been tried out in this way and one of them is for a Dragon test loop which is to be the first experiment in the finished reactor.

Heat transfer and coolant flow have both been studied in specially constructed apparatus. For the latter a replica of the reactor pressure vessel was made in steel and a dummy core inserted. Apparently no divergences from the expected behaviour of the primary coolant have occurred despite the unusual shape of the vessel and arrangement of the channels.

Principal Contractors and Suppliers

NUCLEAR ENGINEER

NDA—(Nuclear Development Corporation), White Plains, U.S.A., now known as "UNITED NUCLEAR CORPORATION."

ARCHITECT ENGINEERS

BEN—Bureau d'Etudes Nucléaires, Brussels.

SOFINA—Brussels

SOVETREAUX—Liège.

Continental Contractors and Suppliers

ATELIERS BELGES REUNIS. Metallic fabrications and mechanical construction.

ACEC
(Ateliers de Constructions Electriques de Charlerol), Charlerol. Main pumps, control rods, cables, electronic control.

ACEC—LA MEUSE
(Association between Ateliers de Constructions Electriques de Charlerol and Ateliers de Construction de La Meuse, Liège). Reactor vessel.

AGEMA, Brussels. Cranes.

ALUMINIUM UNION, Brussels. Aluminium piping.

ANBUMA, Antwerp. Valves (manufacturer, Biondi), and stainless steel piping.

APRAGAZ, Brussels. Piping and welding control.

ARENDONK, Brussels. Polyethylene pipes.

ASPHALTCO, Brussels. Roofs and lining of tanks.

ATELIERS DE CONSTRUCTION DU CANAL, Genk. Metallic constructions.

AUXELTRA/C.F.E. (Association between Auxeltra, Brussels, and Chemins de Fer et Entreprises, Brussels). Civil engineering.

BIONDI, Milan, Italy. Valves.

BROOM AND WADE, LTD., High Wycombe, England. Compressors and air dryers.

BRUYAUX, Brussels. Diaphragm valves (manufacturer, Saunders).

BURTON, Nogent-sur-Oise, France. Air compressors.

CARNOY-VANDENSTEEN, Ghent. Piping.

CHAUROBEL, Hutzingen. Steel tanks.

CIE DES METAUX D'OVERPELT-LOMMEL, Brussels. Lead.

CITAR, Brussels. Piping.

COCKERILL-OUGREE, Seraing. Steel containment building.

COGEGAZ, Liège. Valves.

COLLARD AND COLETTE, Brussels. Barytes.

CONTIGEA, Brussels. Instrumentation and piping.

CUPREX, Ghent. Fuel tanks.

DESMARQUET, Paris. Demineralization filters.

D'HONDT, Brussels. Tanks.

DONCKERS, Louvain. Valves.

ELECTROFACT, Brussels. Instrumentation.

ELECTRO-NAVALE AND INSUTRIELLE, Antwerp. Electrical work.

EMBA-AGENTUREN, Antwerp. Roto-valves (manufacturer, Allis-Chalmers).

ENGLEBERT, Liège. Joints.

ENSIVAL, Pepinster. Pumps.

FABRICOM, Brussels. Piping and heat exchangers.

FABRIQUE DE FER, Charlerol. Steel sheets.

FORAKY, Brussels. Stainless-steel pieces.

L'HOIR, Angleur. Experimental aluminium heat exchangers.

HONEYWELL CONTROLS, Brussels. Instrumentation.

HYDROBEL, Liège. Instrumentation.

INTEGRA, Liège. Instrumentation (manufacturer: Leeds and Northrup).

KENT CONTINENTAL, Brussels. Venturis.

MARSTON EXCELSIOR, Wolverhampton, England. Aluminium piping.

LA MEUSE, Sclessin, Liège. Flow-test vessel, bottom cover seals.

MAT, Brussels. Instrumentation.

MBLE, Brussels. Health monitoring equipment.

MERCANTILE MARINE ENGINEERING AND GRAVING DOCKS, Antwerp. Tanks and piping.

MEURA, Tournai. Tanks and aluminium vessel.

MINES DE GARROT, Boulogne, France. Shielding barytes.

NEU, Brussels. Ventilation.

NOUVEAUX ATELIERS LEBRUN, Nimy-lez-Mons. Heat exchangers, compressed air tubes.

PICART AND BEER, Brussels. Steel balls for concrete.

PLEUGER, Wijnegem. Instrumentation.

PRODUITS CHIMIQUES ET MINERAUX, Paris. Barytes.

RIHON, Brussels. Air conditioning.

SAINT GOBAIN, Paris. Windows for high activity dismantling cell.

STEGU, Brussels. Instrumentation.

STORK, Brussels. Pumps.

TOLERIES GANTOISES, Ghent. Pool lining and piping.

UDDEHOLM, Brussels. Piping.

UGINE CARBONE, Grenoble, France. Filters.

VAPOR, Brussels. Valves (manufacturer, Fabrivalve Co. of America, Glenfield).

VINCOTTE, Brussels. Erection and welding control.

VYNCKIER, Antwerp. Electrical equipment.

WEISSHAUPT, Eupen. Crane.

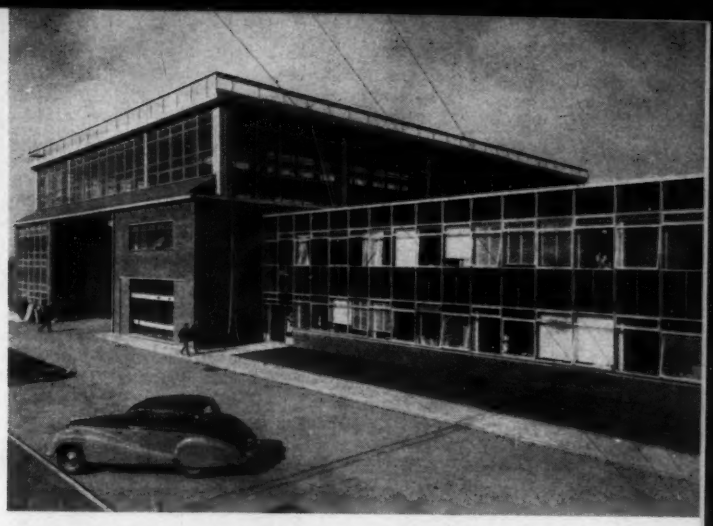
U.S. Suppliers

BADGER MANUFACTURING CO. Expansion joints.

BRUSH BERYLLIUM CO. Beryllium matrices.

SYLVANIA-CORNING NUCLEAR CORP. Fuel elements.

METALS AND CONTROLS. Fuel elements.



The engineering hall with part of the two-storey office building in the foreground.

Berkeley Nuclear Laboratories

BUILT and equipped at a cost of more than £2 million, CEGB's new nuclear laboratories at Berkeley were officially opened on May 29. Coinciding with the opening, CEGB organized a four-day conference on the effects of radiation damage (see page 283 of this issue).

The new laboratories, which are located just outside the nuclear power station at Berkeley, are a branch of the Generating Board's research and development department which was established three years ago. The Board member responsible for research is Mr. L. Rotherham and the director of the laboratories is Dr. C. P. Haigh.

The first programme of work will be essentially concerned with the present civil power programme; the principal investigations will be concerned with the behaviour of reactor materials and the effects of radiation on fuel element life (Materials division); physics aspects of nuclear power generation (Physics division); and the solution of the numerous engineering problems that arise during construction of a power reactor station (Engineering division). These three research divisions each have a separate head of department who is responsible to the director.

In plan form the Berkeley Laboratories resemble the letter "E." Radioactive materials are handled in the shielded area and the laboratory wing (shown on the right in the figure on the next page), on the north side; the administration and office block links these areas with the engineering hall on the left of the diagram. In addition there is a boiler house, a maintenance block and, some distance away on the river bank, a staff restaurant. The total floor area of the laboratories is about 100,000 sq. ft.

There are a number of special features about the shielded area and the laboratory wing. Normally, access to them is through the change rooms in which members of the staff change into protective clothing and ultimately ensure that they are free from contamination before leaving. All protective clothing is washed in the laundry which is adjacent to the change rooms. An air-conditioning system supplies warm fresh air to the buildings and extracts it through filters which remove any possible radioactivity before discharge into the atmosphere through a 75-ft chimney. This ventilation system is designed to maintain a slightly negative pressure inside the radioactive handling building. All drains from this area lead to hold-up tanks where the effluent can effectively be freed from any traces of radioactivity before final discharge.

The shielded area is approximately 108 ft long by 100 ft wide. It has been designed essentially to provide facilities for the laboratories materials division to undertake post irradiation examination of fuel elements and test specimens, such as steel, from reactors. The layout and equipment have been designed to receive fuel elements in transport flasks containing up to one million curies of radioactive material and to carry out examinations which involve the reduction to specimens whose activity is sometimes less than one curie.

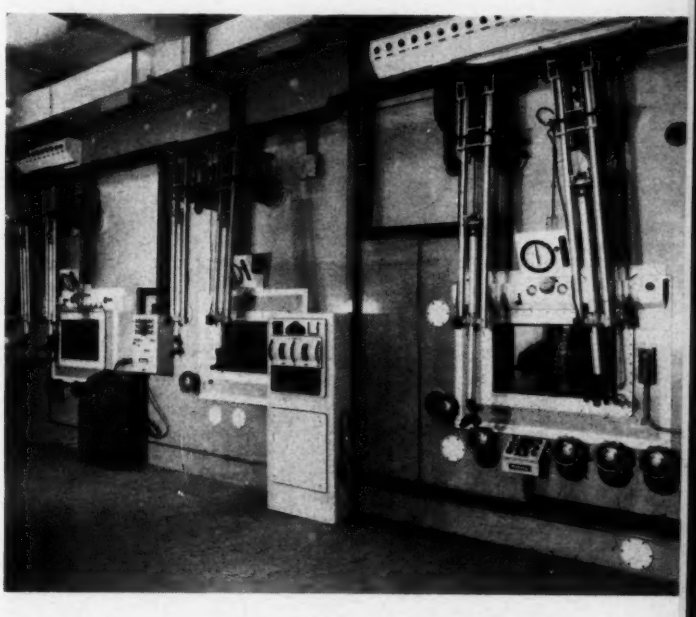
Fuel elements for examination arrive at Berkeley in large shielded flasks, each weighing about 50 tons. These flasks are off-loaded by a crane and deposited in the pond which is 20 ft square by 29 ft deep. When required for examination a fuel element is removed from the flask under water and taken by conveyor through a shielded tunnel into the first of a suite of three caves.

The caves are formed of half-inch thick mild steel with massive outer concrete walls over 5 ft thick. They are each about 9 ft square and 14 ft high, and are separated by power-driven, sliding partitions 2 ft 3 in thick. Observation from the front is through windows formed of lead glass filled with a zinc bromide solution. At the rear, giving access to the maintenance area, are massive concrete sliding doors.

The caves have been designed so that whilst the dose rates in the operating area remain well below permissible levels, any one cave may contain an activity of 50,000 curies with 10,000 curies in each of the other two caves. All operations within the caves are carried out by remote control and each cave has its own manually operated, remotely controlled Mk. 7B manipulator. In addition, there is a GEC power-driven manipulator which runs on overhead rails and can be used in any of the three caves.

In the first cave the fuel element is removed from its outer can and is inspected visually. From there it is transferred to the second cave, which is equipped for metrology and radiographic examination. If an inspection to detect minute cracks in the fuel element can is required, the fuel element is transferred to the third cave which is equipped with modified leak detection equipment. Following these procedures, the fuel element is returned to the first cave where two cutting machines

Operating face of the set of three caves showing the controls of the master/slave manipulators.



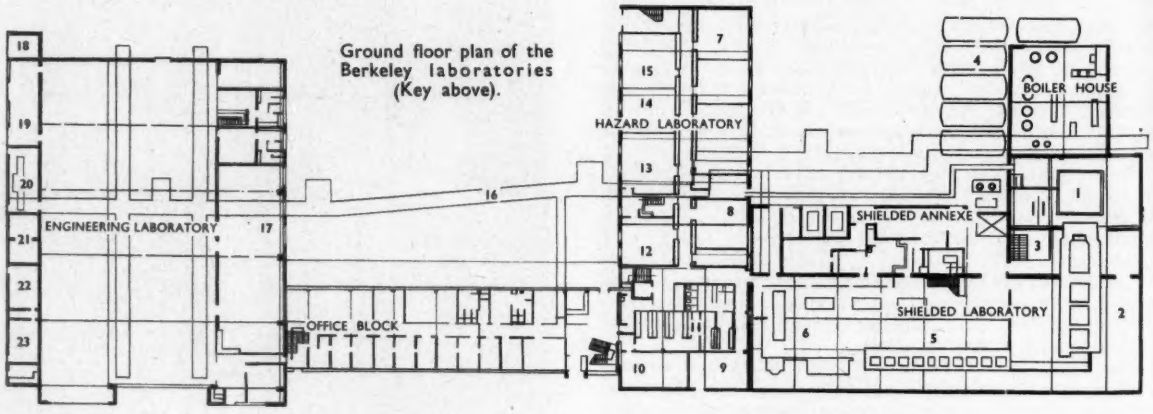
remove the alloy can. The uranium bar can now be sectioned and small pieces transferred to the third cave for the preparation, using a milling machine, of specimens for mechanical tests and metallographic examinations.

From the cave suite specimens are transported by a shielded railway to a suite of nine cells running at right angles to the caves. Eight of the cells are 5 ft wide, 4½ ft deep and 6 ft high and are separated from each other by fixed heavy concrete partitions 20 in thick. The ninth cell is of double width. The shielding at the front of the cell consists of a wall of heavy concrete 2 ft thick, 2 ft 9 in high on which is a lead wall 10 in thick with inset lead glass viewing windows. The roof is of steel, 10 in thick, pierced to take manipulators and the rear wall is of normal concrete, 4 ft thick with removable plug doors.

Two cells are used for machining operations on test specimens, a third houses an Instron tensile testing machine and another is employed for metrology. The double cell is devoted to the steel specimen monitoring programme. In another cell there is an encapsulating rig for sealing specimens in silica and several furnaces for subsequent heat treatments. There are also two general-purpose cells in which short term experiments are carried out, and a cell which is used for storage and general decontamination work.

The laboratory wing, which runs at right angles to the shielded area, is a three-storey building providing laboratory accommodation on the ground and second floors, with all services and ventilation ducting on the mezzanine floor. Work in the laboratory wing is centred on fundamental investigations into the behaviour of reactor materials. This wing provides facilities chiefly for the materials division but it also houses the solid state physics and the graphite sections of the physics division. On the ground floor accommodation is provided for an analytical chemistry laboratory, two general metallurgy laboratories, a hazard chemistry laboratory (equipped with its own special change room), laboratories for work in solid state physics and a laboratory shared between health physics and nuclear instrumentation. Finally there is a balance room, a store room and a glass blower's workshop. The second floor houses the graphite laboratory and laboratories for electron microscopy, physical chemistry, X-ray diffraction, metallography, spectrometry and general metallurgy. There are also photographic dark rooms, a dark operations room, a furnace and fabrication facility, a graphite furnace room and a small general workshop, for work which must be carried out within the radioactive areas.

KEY to layout diagram below: 1.—Reception area and storage pond. 2.—Hot cave operating face (served by 10 ton gantry). 3.—Effluent treatment. 4.—Hot water storage vessels. 5.—Group of hot cells. 6.—Dry boxes. 7.—Physics instruments. 8.—Analytical chemistry. 9.—Active laundry. 10.—Glass blowers. 11.—Change room. 12.—Hazard metallurgical laboratory. 13.—Hazard chemical laboratory. 14.—Health physics laboratory. 15.—Nucleonics laboratory. 16.—Underground service duct. 17.—Machine shop and stores. 18.—Transformer. 19.—Compressor house. 20.—MV switchgear. 21.—Pair of 1000 KVA transformers. 22.—Switchgear. 23.—11 kV supply.



Ground floor plan of the Berkeley laboratories (Key above).

The shielded area with reception hall on the left.

The engineering hall forms the southern end of the laboratories and is 160 ft long, 115 ft wide and 60 ft high. It provides accommodation for the main workshops of the establishment, the large rigs of the engineering division and for numerous laboratories of both the physics and the engineering divisions. At present it also houses the main laboratory stores.

On the main floor of the engineering hall there are two rigs for the investigation of the heat transfer properties of fuel elements. The rigs contain fuel element cans fitted with electrical heaters and they employ atmospheric air as a coolant. A closed circuit, pressurized rig, using carbon dioxide as the coolant is shortly to be added for heat transfer studies under reactor conditions, and a rig for endurance tests on fuel elements contains a dummy reactor channel in which complete fuel elements can be tested. A further facility is a visual flow rig in which water, loaded with a fluorescent dye, is pumped past a fuel element held in a Perspex tube to demonstrate the fluid flow patterns around the element.

CONTRACTORS

Architect: Harry S. Fairhurst and Son.

Consulting Engineers: Mechanical: G. H. Buckle and Partners. Civil, Mechanical and Structural: Southern Project Group, CEGB.

Main Contractors: Civil: Tersons, Ltd. Ventilation and Heating: G. N. Haden and Sons, Ltd. Electrical: N. G. Bailey and Co., Ltd. Steelwork: Modern Engineering (Bristol), Ltd.

Contractors for Shielded Area: Design and supply of equipment including Mark 7B manipulators and special remotely-controlled machinery; H. M. Hobson, Ltd., Wolverhampton.
Periscopes: Barr and Stroud.
Power manipulator: GEC.
Zinc bromide windows: Mendip (Chemical Engineering, Ltd.).
Model 8 master/slave manipulators: Nuclear Equipment, Ltd.
Glass for Z.B. windows: Pilkington Bros., Ltd.
X-ray equipment: Solus Schall, Ltd.
Constructional steelwork: Westwood and Wright, Ltd.

Effects of Radiation Damage

The CEGB's International Conference on the Properties of Reactor Materials and the Influence of Radiation

IN spite of the proximity of the Berkeley Nuclear Power Station now scheduled to begin fuel loading either this month or early next month, delegates to the Conference (held principally in the Grand Hall of Berkeley Castle) concerned themselves more with the mechanisms of radiation damage and, in particular, lattice defects rather than the micro and macroscopic effects which are of more concern to the reactor designer, constructor and operator. It was made clear that our knowledge of the mechanisms of radiation damage to even the most simple materials is very far from complete and with the more heterogeneous mixtures such as graphite, we are a long way from being able to predict with any confidence from theoretical grounds the behaviour of the material under any given set of conditions.

Not that the description of the environmental conditions or their measurement in a given reactor system is at all easy. Bearing in mind that neutrons with an energy below 0·01 MeV can be neglected, multi-group diffusion theory should lead to a fairly good assessment of the damage flux, particularly for fast reactors, but there is no reason why the method should not also apply to thermal reactors provided the group widths are made smaller than those adopted in normal reactivity calculations. The most satisfactory method for fine structure is a Monte Carlo method where the final limitation is the accuracy of the available nuclear data. Where the attenuation of the primary flux is large as in the pressure vessel region one would prefer the moment method. However nervous designers and operators may feel of theoretical calculations, the accuracy is almost certainly better than can be obtained by dosimetric techniques based on threshold detectors, photographic plates, etc. It was suggested that semi-conductors may provide the ultimate answer to measurement but this is certainly looking into the future.

Even if flux can be described quite accurately (and the language of the description is generally acceptable) assessment of damage is still very difficult. Measurements taken on one material at different positions in a reactor or in different reactors cannot be translated in radiation damage terms to another material or another system. So far as the gas cooled graphite moderated reactors are concerned, continuous work on Bepo and the Calder reactors has allowed a self-consistent programme of calculation and measurement to be built up which permits extrapolation to the civil reactors with a fair degree of confidence, although there is still the problem of flux rate which makes the forecasting of damage even in basicly similar reactors difficult when flux levels change appreciably. The damage in graphite can be assessed quite accurately up to a temperature of 300°C by its electrical resistivity and this has proved to be a very sensitive method of measurement. Although the damage in graphite seems remarkedly linear with integrated dose there is strong evidence that the self-annealing process is essentially time dependent (as well as temperature dependent) so that speeded up measurements in high flux loops will give pessimistic results.

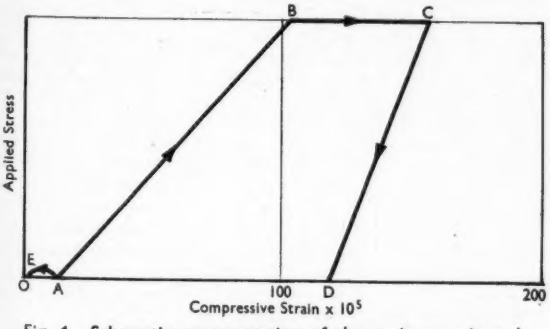


Fig. 1. Schematic representation of the strain experienced by specimen A B.

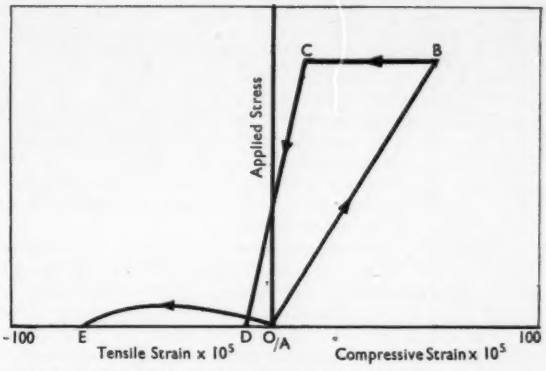


Fig 2. Schematic representation of the strains experienced by specimen Fl.

We shall not attempt to summarize the lengthy discussions on the mechanisms of damage although some reference must be made to the work at Brookhaven by Dr. Vineyard who has been able to demonstrate a focusing method of successive displacements so that in a face-centred cubic body, for example, the initial recoil atom displaces a neighbour along the diagonal and takes its place, the displaced atom doing the same with the next diagonal and the process becoming more and more closely focused along this diagonal so that the initial recoil results in a displacement several lattice distances away. There will be complicating disorders at the beginning of the collision series before the focusing is fully effective, and local to the affected atoms high temperatures will be generated (the thermal spike). It still does not seem clear, however, why there is a threshold energy of 20 eV before an atom can be displaced, although the displacement energy is of the order of 5 eV only.

Many methods of investigating point imperfections were discussed including a brief account by Dr. Mendelssohn of the Clarendon laboratories of work on super conductivity, where measurements at low temperatures of thermal conductivity against temperature in the presence of a magnetic field and also in its absence allow an assessment to be made of the electron conduction and phonon conduction and hence separating the effects of point imperfections and dislocations.

Graphite

Not all the material presented at the Conference was concerned with the academic aspects only. Dr. Jenkins, now of the Berkeley laboratories reported on measurements made when at Culcheth on the effect of irradiation on strain in stressed graphite, the experiments having been performed in fuel element positions in the Herald reactor at Aldermaston. Typical results are shown in Figs. 1 and 2 where AO is the permanent set due to stressing before irradiation, AB is the strain incurred before irradiation, BC is the creep at constant stress during irradiation and CB is the release curve after irradiation, whilst AE is the gross strain in a specimen free of stress. Analysis of these curves is clearly very difficult owing to the very large increase in modulus of elasticity and the presence of irradiation

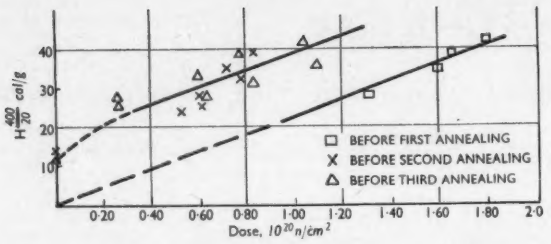


Fig. 3. Increase of energy v. dose at an irradiation temperature of 100° C.

growth, sufficient in the second case to reverse the direction of creep. Results so far obtained seem to indicate that the viscous creep is of the order of 2 000 ppm under 1 700 psi with 10^{20} nvt nickel dose, and it may be greater in perpendicular specimens than in parallel. Permanent set is released by irradiation and the irradiation increases the modulus.

Dr. Rappeneau of Saclay reported on the different behaviour of the graphite in the G-1 reactor after the first annealing. Due to the low irradiation temperature (40° to 150°C) the G-1 reactor must be annealed fairly frequently, the energy stored being measured by the overall amount released when annealed at 400°C and also by differential thermal analysis which gives the energy release per degree rise in temperature between room temperature and 800°C.

The release rate actually reaches a peak between 200° and 300°C depending upon the irradiation temperature. Although slight residual energy is left in the graphite after annealing, on re-irradiation there is initially a sharp rise in the rate of energy stored following which the rate of storage settles down to the original figure. Fig. 3 is an example of one set of results where the irradiation temperature is 100°C showing the marked difference between the first and second irradiations but only a small difference between the second and third. Results were also presented of the change in hardness of graphite under irradiation as measured on specimens cut from the walls of the channel. Fig. 4 shows the correlation between hardness and apparent density and Fig. 5 the relative change in hardness for different irradiation doses at different irradiation temperatures. The hardness could be annealed out by raising the temperature, the rate of recovery corresponding to the Wigner release curve and the original hardness being recovered after annealing at 900°C.

A theory of the growth in graphite was presented by Mr. Buckley and Mr. Makins of Harwell. They produced a persuasive explanation of how the interstitials will cluster on one plane while the vacancies will collect in the plane at right angles. As a result the graphite will tend to grow in one direction and contract in the direction at right angles. Energy considerations and electron micrograph evidence support this theory.

In view of the critical nature of the radiation induced corrosion of graphite in CO_2 atmospheres under AGR conditions it was disappointing that corrosion discussions were centred almost entirely on the high temperature reactors with inert coolants where the thermal mechanism is dominant, although the dependency of strength upon oxidation is of relevance to this reactor system. With 10% burn-off the compressive strength goes down to half and the graphite in an AGR core after 20 years, on this basis, would have a compressive strength of only one fifth of the original. From the reactor point of view, however, the mass transfer of carbon may be more important as the deposition on structural materials leading to graphitization could be disastrous in terms of ductility and impact resistance. Some control of the oxidation has been achieved by silicon carbide and pyrolitic carbon coatings but confidence in their reliability must be in doubt.

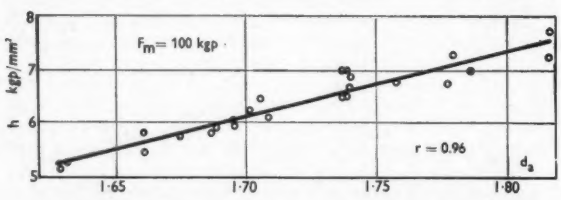


Fig. 4. Hardness v. apparent density perpendicular to extrusion (curves for parallel direction are similar).

Uranium

Surprisingly little interest was shown in the measurements of growth reported by M. Englander and M. Stohr of Saclay on various types of uranium fuel elements irradiated in France. The behaviour of as-cast uranium alloy fuel containing 1% molybdenum is described as spectacular, no deformation having been observed for one type of fuel element (not unlike the Calder) after a burn-up of 10 000 MWd/t. In the molybdenum alloys of uranium the matrix of U_α grains is filled by a second phase (U_γ containing 14% by weight of Mo) this being in the form of fine parallel platelets. Although the aggregate is much less fine with the 0·5% than with the 1 to 2% Mo the behaviour of the 0·5% alloy is nevertheless still excellent after a burn-up corresponding to 4 200 MWd/t and a hotpoint of 450°C. The 1% alloy is considered to give the most dependable

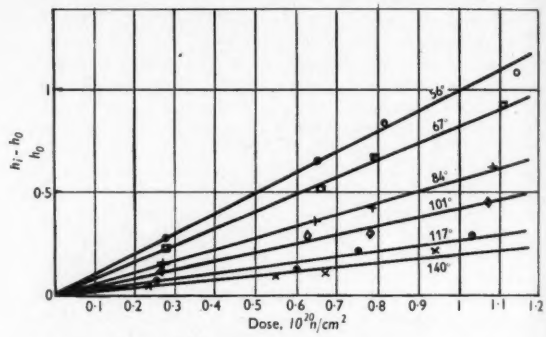


Fig. 5. Increase of hardening co-efficient v. dose at different irradiation temperatures.

results but there is still of course a considerable reactivity penalty and the work reported by M. Mustelier *et al.* on the swelling of uranium molybdenum alloys emphasizes the importance of thermal treatment and raises doubts about their application when temperatures of 450°C or more are involved. In the experiments reported (see Table 1) 19 U-Mo alloys containing 1, 2 and 3% Mo were irradiated in a loop in EL-3 at temperatures between 410° and 500°C, the irradiation including 17 thermal cycles. The alloys had been prepared by homogenizing in the gamma phase and then quenching and annealing at temperatures between 450° and 600°C. The alloy was 10% enriched and the burn-up varied between 0·37 and 0·55%.

From Japan Dr. Hasiguti gave an account of a theoretical explanation of the phenomenon of swelling relating in particular to the enhancing effect of thermal cycling. This postulates that even a small change in temperature will allow a dislocation line to move and this will be caught by the gas bubbles and will in effect form a pipeline between the larger bubbles and the smaller bubbles allowing an accelerated growth of the larger bubbles and the disappearance of the smaller. Dr. Greenwood of the Berkeley laboratories discussed results on the irradiation of a sample of alpha-uranium with a temperature gradient along the bar and interpreted the final measurements of bubble size and distribution as contradicting the theory that if uranium were first irradiated at a low temperature and then at a high temperature the high temperature distribution of bubbles would correspond to the low temperature irradiation.

Such a procedure would in any case be only possible in a reactor where provision was made for sequential charging from the cool end of the fuel channel.

A problem of considerable interest in the development of bursts is the oxidation of uranium in a CO_2 atmosphere and

TABLE 1

Alloy	Thermal treatment	Irradiation temp. Mean	Irradiation temp. Maximum	Burn-up	Relative volume change, %
UMo 1%	450	410	420	0·37	4·1
	500	461	472	0·48	16·7
	550	495	500	0·525	22·1
	600	490	495	0·555	23
UMo 2%	450	410	420	0·37	3·64
	500	461	482	0·475	16·3
	550	495	500	0·525	14·4
	600	490	495	0·555	24·9
UMo 3%	450	410	420	0·37	2·2
	500	461	472	0·48	12·9
	550	488	492	0·540	57·5
	600	490	495	0·555	44·5

theories were presented relating to the significance of the plasticity of the initially formed oxide film and the electron conduction properties of the film. It has been found for example that raising the uranium temperature from 800° to 1 000°C in fact reduces the oxidation rate and this is believed to be almost certainly due to the increase in plasticity of the film which allows it to maintain its protective coating without cracking for a longer period. The contamination of the coolant by hydrogen and water vapour is an important factor, the corrosion rate increasing linearly with the water content in CO_2 up to 500 ppm between 350° and 500°C.

Alloyings and coatings have both been tried to reduce the rate of attack of uranium by CO_2 and 1% molybdenum alloying may reduce the rate by a factor of four, but this is still only a marginal improvement in this context and a great deal of further development work is necessary.

Steels and Boron

A great quantity of information has been collected on the effect of irradiation on the plastic properties of solids. With neutron irradiation there is generally a great increase in the yield strength, the increase being sensitive to the testing temperature. The law governing the increase can be expressed either as $\phi^{\frac{1}{2}}$ (where ϕ is the flux) or as $\phi^{\frac{1}{4}}$ plus a saturation effect. The mechanism of the damage is in doubt but there is a theoretical preference for the second law and the half-power relationship. In practice, however, the difference is not greatly marked.

It was pleasing to note that the Russians in their investigation of the shift of the ductile-brittle transition temperature for mild steels obtained results which fell in the range 22·5 $\phi^{\frac{1}{2}}$ and 50 $\phi^{\frac{1}{2}}$ agreeing nicely with Cottrell's estimate of the maximum shift being 55 $\phi^{\frac{1}{2}}$. With a chrome-nickel-molybdenum-vanadium steel at 350°C somewhat smaller shifts in transition temperature have been observed than with the mild steel, whereas with stainless steel, whilst strength has increased, ductility has not been greatly affected.

Boron bearing materials present their own particular problems because of the release of helium through the B(n,α) reaction which can lead to increased brittleness, swelling and complete pulverization of the material. An extensive survey of the effects of radiation was presented by Mr. Holden *et al.* of U.S. General Electric which included the effects on elemental boron, boron carbide, borides, cermets, dispersions and boron oxide compounds. The most commonly used material is boron carbide where swelling is negligible up to 10% burn-up and is about 1% after 15% burn-up; after 16 to 26% burn-up samples have become completely granulated. We shall not, however, attempt to review further what was already a highly condensed contribution.

Radiation Monitoring for the Protection of Personnel

International Survey of Equipment designed to detect and measure ionizing radiation

THE tabulated data in this and the following pages has been compiled from answers to a questionnaire sent to all known radiation detection equipment manufacturers in the world. Although the tables are not necessarily comprehensive (replies are still coming in at the time of going to press), they do present a representative cross-section of the many different types of monitor in production now. A further list of makers' names and specifications will be published at a later date.

β γ n FILM BADGES

Model	Film type	Overall size	Sensitive areas: Screen	Sensitive areas: Exposed area	Measuring range: β	Measuring range: γ	Measuring range: n	Radiation discrimination
ELECTRONIC MACHINE CO., LTD., 41 Lodge Road, West Croydon, Surrey.								
EMC/1	Kodak Ilford PM1, PM3	1¼ in×1⅝ in	1⅛ in×1⅛ in	⅞ in×⅛ in	20 mr–5 R Approx. figures only, dependent on emulsion type used	2·5 mr–8 R	15 mr–10 R	±>10%
EVANS ELECTROSELENIUM, LTD., St. Andrews Works, Halstead, Essex.								
This company manufacture the Mosalen Densitomster for measuring the transmission density of film badge negatives. 230 v, 50 c/s, a.c. Price: £120.								
ISOTOPE DEVELOPMENTS, LTD., Bath Road, Beenham, Reading, Berks.								
Type 1880 with accessory Type 2031								Combined charger and reader for BD11 chambers comprising:—electrometer type 1880—£202; charge and read unit type 203—£30 approx. A mains operated bench mounting instrument.
RADIATRON, 7 Sheen Park, Richmond, Surrey.								
Normal badge	Adox or Kodak	45×56×6 mm	2×0·5 Cu 2×1·2 Cu 2×0·05 Cu 2×0·5 Pb	13×16 mm 16×16 mm 13×16 mm 5×12 mm				Between 40 kV and 2 MeV
Fast neutron badge		57×80·5×7 mm	1×0·5 Pb 2×1 Cd 2×1·2 Sn 2×0·6 Sn 2×0·5 Cu 2×0·05 Cu 2×0·5 Pb	6×15 mm 7·5×19·5 mm 7·5×19·5 mm 8·5×11·5 mm 8·5×11·5 mm 7·5×15 mm 7·5×15 mm				

POCKET DOSIMETERS

Model	Range: Scale range	Range: Min. dose	Range: Max. dose	Accuracy	Energy range	Size: Linear dim.	Size: Weight	Price	Charger: Type	Charger: Price	Reader: Type	Reader: Price
ATOMIC ACCESSORIES, INC., 811 West Merrick Road, Valley Stream, N.Y., U.S.A.												
DDR-862	0–200 mr			±10%	80 keV–2 MeV ±20%	$4^{13}/_{32}$ in × $1^{7}/_{32}$ in	1¼ oz		CH 800		Direct reading	$38·00
609	0–120 mrem n only			±10%		$4^{13}/_{32}$ in × $1^{7}/_{32}$ in	1¼ oz		CH 800		Direct reading	$45·00
GENERAL RADIOLOGICAL, LTD., County Building, Honeypot Lane, Stanmore, Middx.												
									NE 050·02 transistorized	£10.0.0		
ISOTOPE DEVELOPMENTS, LTD., Bath Road, Beenham, Reading, Berks.												
Pocket Dosimeter	0–20 mr, or 0–200 mr, or 0–20r			5% down to 18 keV		6⅜ in × 2⅜ in × $^{15}/_{16}$ in	10 oz		Not required, battery operated		Not required, self-contained electronic instrument with meter indication	
WILLIAM B. JOHNSON AND ASSOCIATES, INC., P.O. Box 415, Mountain Lakes, New Jersey, U.S.A.												
J–49	200 mrem	1 mrem		±10% γ, ±20% n for for all 8 dosimeters	80 keV–2 MeV for all 8	4½ in	½ oz	$45·00	Model 5	$49·50	All are direct reading type	
J–50	200 mr	1 mr						$38·00				
J–51	5 r	1 r						$48·00	Model 24	$49·50		
J–52	10 r	1 r						$48·00				
J–53	20 r	1 r						$48·00				
J–54	50 r	1 r						$48·00				
J–55	100 r	1 r						$48·00				
J–56	600 r	1 r						$48·00				
N.V. PHILIPS' GLOEILAMPENFABRIEKEN, Eindhoven, Netherlands.												
37484		0–	200 mr		0·04–0·115 MeV				37472		37472	
RADIATION EQUIPMENT & ACCESSORIES CORP., 665 Merrick Road, Lynbrook, N.Y., U.S.A.												
Scram–1	Audible signal	Bgd.: 1 pulse/2 min 1 r/h: 2 800 c/s				6 in × ¾ in o.d.	3·5 oz	$75	Not required			
RADIATRON, 7 Sheen Park, Richmond, Surrey.												
Condiognom double chamber	10–100, 100–1 000 mr			±10%		130 mm long, 15·5 mm dia.	30 g	£7.3.0 duty free	Combined—£71.10.0 duty free			
RANK CINTEL, LTD., Worsley Bridge Road, London, S.E.26.												
0·5 r	0–0·5 r			<10 mr error for doses <0·1 r; <10% of scale reading for larger doses	Down to approx. 30 keV mono-chromatic equivalent	5 in long, ⅝ in dia.	1 oz	£7.0.0				
5 r	0–5 r			<0·1 r error for doses <1 r; <10% of scale reading for larger doses		4⅜ in × ⅝ in dia.	1¼ oz	£9.10.0				
RESEARCH AND CONTROL INSTRUMENTS, 207–15 Kings Cross Road, London, W.C.1.												
Philips 37484	0–200 mr				0·04 MeV–0·115 MeV				37472/11		37472/11	
R. A. STEPHEN AND CO., LTD., 120–126 Lavender Avenue, Mitcham, Surrey.												
Aluminium cased:												
P.1164/A	0–200 mr	2 mr	200 mr	±10% of true dose	(Energydependency) ±10% 40 keV/2 MeV	4½ in × 6 in dia.	$1^{1}/_{3}$ oz	(Singly) £10.0.0	P.640	£12.10.0		
P.1164/B	0–500 mr	5 mr	500 mr	±10% of true dose	±20% 40 keV/2 MeV	4½ in × 6 in dia.	$1^{1}/_{3}$ oz	£7.0.0	Pocket transistorized. Charges complete range of dosimeters. Size: $3^{9}/_{16}$ in × 1⅞ in × $^{15}/_{16}$ in Weight: 6 oz.			
P.1164/C	0–5 r	0·05 r	5 r	±10% of true dose	±20% 40 keV/2 MeV	4½ in × 6 in dia.	$1^{1}/_{3}$ oz	£10.0.0				
P.1164/E	0–50 r	0·5 r	50 r	±10% of true dose	20% 40 keV/2 MeV	4½ in × 6 in dia.	$1^{1}/_{3}$ oz	£10.0.0				
P.1164/G	0–150 r	1·5 r	150 r	±10% of true dose	±20% 40 keV/2 MeV	4½ in × 6 in dia.	$1^{1}/_{3}$ oz	£17.10.0				
P.1164/H	0–500 r	5·0 r	500 r	±10% of true dose	±20% 40 keV/2 MeV	4½ in × 6 in dia.	$1^{1}/_{3}$ oz	£17.10.0				
P.1164/J	0–1 000 r	10·0 r	1 000 r	±10% of true dose	±20% 40 keV/2 MeV	4½ in × 6 in dia.	$1^{1}/_{3}$ oz	£17.10.0				
Brass cased:												
P.1051/A	0–200 mr	2 mr	200 mr	±10% of true dose	±10% 120 keV/2 MeV	4½ in × 6 in dia.	1⅔ oz	£10.0.0				
P.1051/B	0–500 mr	5 mr	500 mr	±10% of true dose	±10% 120 keV/2 MeV	4½ in × 6 in dia.	1⅔ oz	£7.0.0				
P.1051/C	0–5 r	0·05 r	5 r	±10% of true dose	±10% 120 keV/2 MeV	4½ in × 6 in dia.	1⅔ oz	£10.0.0				
P.1051/E	0–50 r	0·5 r	50 r	±10% of true dose	±10% 120 keV/2 MeV	4½ in × 6 in dia.	1⅔ oz	£10.0.0				
P.1051/G	0–150 r	1·5 r	150 r	±10% of true dose	±10% 120 keV/2 MeV	4½ in × 6 in dia.	1⅔ oz	£17.10.0				
P.1051/H	0–500 r	5·0 r	500 r	±10% of true dose	±10% 120 keV/2 MeV	4½ in × 6 in dia.	1⅔ oz	£17.10.0				
P.1051/J	0–1 000 r	10·0 r	1 000 r	±10% of true dose	10± 120 keV/2 MeV	4½ in × 6 in dia.	1⅔ oz	£17.10.0				
All dosimeters are self-sealing, hermetically sealed, and impervious to pressure and temperature variations from −40°C to 50°C.												
TRACERLAB, INC., 1601 Trapelo Road, Waltham 54, Mass., U.S.A.												
K–112, direct reading	0–200 mr		200 mr	<5% above 250 keV		3⅜ in × ½ in	approx. ½ oz	$48·60	K–145c	$64·80	Not required	
THE VICTOREEN INSTRUMENT CO., 5806 Hough Ave., Cleveland 3, Ohio, U.S.A.												
362	No scale		200 mr	See charger-reader	30 keV–1·2 MeV	5½ in × ½ in dia.	½ oz	$9·00	Model 687	Electronic charger-reader		$295·00
									Model 287	String electrometer charger-reader		$155·00
541/A	0–200 mr		200 mr	±10%	45 keV–2 MeV	4 in × ½ in dia.	½ oz	$38·00	Transistorized	$40·00		
656/A	0–500 mr		500 mr	±10%	50 keV–2 MeV	4 in × ½ in dia.	½ oz	$49·00	Model 2000/A			

LIQUID MONITORS

Model	Application	Continuous or Batch	Sample volume	Detector	Indicator	Ranges	Sensitivity β	Sensitivity γ	Accuracy	Response time	Weight	Price
EKCO ELECTRONICS, LTD., Ekco Works, Southend-on-Sea, Essex.												
N645 rate-meter with N674 scintillation counter, N665 γ head	Dipping probes	Continuous	Max. depth 3 ft	γ (N674 scintillation counter, N665 γ head)	N645 field ratemeter	0–10 counts/s 0–100 counts/s 0–1 000 counts/s	5 c/s for 5×10^{-5} μc/ml of Sr^{90} in water	10^{-4} and 10^{-5} c/μc of most gamma emitters in water	±5%	Variable, 4, 8, and 20 s on following count ranges 10 c/s 4 and 20 s, 100 c/s 4 and 8 s, 1 000 c/s 4 s	7 lb	γ only £190. β only £128.10.0 β/γ £208.10.0
N645 rate-meter with N675 beta head				β (N675 head using B12 GM tube)	N645 field ratemeter							
ELLIOTT NUCLEONICS, LTD., Century Works, Lewisham, S.E.13.												
ND 2151 High sensitivity water monitor	Detects radioactivity by ion-exchange principle	Continuous record samples monitored at rate of 20 cm^3/10 min		GM tube type B12Ha	Local recorder 4 in strip chart. Remote recorder if required	As required				10 min, i.e., sampling time	70 lb	Basic £586
Cooling water monitor	Reactor cooling water circuits	Continuous	Dependent upon pipe line size	Photo-multiplier tube	4 in indicator. Remote recorder if required	As required						Upon application
FRANKLIN SYSTEMS INC., P.O. Box 3250, West Palm Beach, Florida, U.S.A.												
15, dip	Portable survey	Batch	1 litre	Scintillator	Meter				±5%	1 s	35 lb	
30	Water monitor	Continuous		Scintillator	Meter		2×10^{-6} μc/ml		±5%	1 s	30 lb	
45	Underwater survey	Continuous		Scintillator	Meter		5×10^{-7} μc/ml	5×10^{-9} μc/ml	+5%	10s	50 lb	
90–2	Large well	Batch	45 litres	Scintillator	Meter			10^{-4} μcK^{40}	+5%	30 s	4 500 lb	
WILLIAM B. JOHNSON AND ASSOCIATES, INC., P.O. Box 415, Mountain Lakes, New Jersey, U.S.A.												
WM	Water monitoring	Continuous	100 cm^3	Glass jacketed GM tube	Linear/log count rate-meter	0–10^6 counts/min				5 s full scale	50 lb	$1 000
NUCLEAR ENTERPRISES (G.B.), LTD., Sighthill, Edinburgh 11, Scotland.												
NE 5502A	For β and γ emitters in liquids or gases	Continuous		Plastic scintillator spiral flow cell							90 lb	£240
NE 8105	Fall-out activity measurement			Plastic phosphor scintillator								£8 500 approx.
PANAK EQUIPMENT, LTD., Holmethorpe Industrial Estate, Redhill, Surrey.												
TR 56 with β probe	Dipping counter	Batch		Thin glass-walled Geiger counter	2 in dia. meter	0–10k and 0–25k counts/min			±10%	1 and 6 s	3½ lb	£50
PLESSEY NUCLEONICS, LTD., Weedon Road, Northampton.												
Milk monitor PNI 1085	Measurement of activity in milk	Batch	No less than 4 gal in a 10 gal milk churn	Thin-walled GM probe B12H	Moving coil meter	0–3 and 0–200 infant tolerances	5×10^{-7} c/l			20 s on 0–3 and 1 s on 0–200 infant tolerance range	15 lb	
Effluent monitor PNI 1046	Measurement of activity in liquid effluents	Continuous	200 cm^3	Thin-walled GM tube for β/γ activity. Scintillator counter for α activity	Log calibrated meter	0·3 to 3 000 counts/s	Background doubled with a specific activity of 10^{-9} c/l of Sr^{90}; or 10^{-7} c/l of C^{137}.	10^{-7} c/l			350 lb	
TRACERLAB INC., 1601 Trapelo Road, Waltham 54, Mass., U.S.A.												
MWP–2	βγ monitoring	Continuous	1 022 cm^3, max pressure; 30 psig	β scintillation or γ scintillation detector	Ratemeter, strip-chart recorder, alarm circuits	Up to 10^6 counts/min				Immediate	450 lb approx.	$2 560 approx.
MWP–3	High level γ monitoring	Continuous	0·9 cm^3, max pressure: 3 000 psig	γ scintillation detector	Ratemeter, strip-chart recorder, alarm circuit	Up to 10^6 counts/min		Co^{60}: 5×10^{-4} μc/cm^3		Immediate	325 lb approx.	$2 370 approx.
MWP–4	β monitoring	Continuous	75 in^3, max pressure: 15 psig	Large area βγ GM detector	Ratemeter, strip-chart recorder, alarm circuit					Immediate	680 lb approx.	$2 400 approx.
MWP–5	α monitoring	Continuous	230 cm^3, max pressure 5 psig	α scintillation detector	Ratemeter, strip-chart recorder, alarm circuit					Immediate	215 lb approx.	$3 000 approx.
MWP–1A	Fission product water monitoring activity of short-lived iodine.	Continuous	Flowrate: 0–200 cm^3/min; max inlet pressure: 150 psig	γ scintillation detector measuring activity in anion column	Precision log ratemeter with spectrometer; strip-chart recorder, alarm circuit	Up to 10^6 counts/min				1 min delay from water-inlet to anion column; from 10 min to reach initial equilibrium	535 lb	$6 000 approx.

HAND AND FOOT

Model	Single/double hand/foot	Radiation measured	Detector	Preset alarm levels			Meter indication			Integrating time	Accuracy	Equipment size	Price
				α	β	γ	α	β	γ				
CONSTRUCTIONS RADIOELECTRIQUES ET ELECTRONIQUES DU CENTRE (C.R.C.), 19 Rue Daguerre, St. Etienne (Loire), France.													
CFA III	Double hand	α	Scintillator							10 s	20%	0·70 m high 0·50 m wide 0·40 m deep	5 700 NF
EMI ELECTRONICS, LTD. (Instrument Division), Blyth Road, Hayes, Middx.													
Type 1	Double hand with clothing and foot probes	α β γ	Scintillation counters Geiger for β γ clothing	10^{-4} μc per hand	3×10^{-3} μc per hand	0·5 mr/h per hand	0–1–2 mpl	0–1–2 mpl	0–1–2 mpl	5 s	5% (Electronic)	60×31×19 in	£2 200
HM–2	Single hand	α β γ	Scintillation counters	10^{-4} μc per hand	3×10^{-3} μc per hand	0·5 mr/h per hand	0–1–2 mpl	0–1–2 mpl	0–1–2 mpl	5 s	5% (Electronic)	17×15×16 in	£700
EBERLINE INSTRUMENT CORP., P.O. Box 279, Santa Fe, New Mexico, U.S.A.													
HFM–2 AHM–10	Double hand/ foot, clothing	β γ	G-M tubes					4 Count rate ranges		2–10 s			$3 075 $1 500
WM. B. JOHNSON AND ASSOCIATES, INC., P.O. Box 415, Mountain Lakes, New Jersey, U.S.A.													
BNL	Double hand/ foot	β γ	G-M tubes							0–1 min	±10%	3 ft wide 6 ft high 4 ft deep	$2 000
RESEARCH AND CONTROL INSTRUMENTS, LTD., 207-15 King's Cross Road, London, W.C.1.													
L 310 Series (Mullard Equipment, Ltd.)	Unitised hand and clothing	α β γ	G-M tubes and scintillation counter		Variable		In mpl's for hands, c/s for clothing			5 s	10%	Various	
SELO-SOCIETA ELETTRONICA LOMBARDA, Via Monfalcone 12, Milano, Italy.													
		α β γ	G-M tubes and scintillation counter	Variable	Variable	Variable	Accumulation of counted pulses on electromechanical counters					180×50×50 cm	

NEUTRON MONITORS (GENERAL)

General description	Model	Mounting	Indicator		Power		Size		Price
			Audible Type	Meter Linear/log	Consumption	Supply	Linear Dim.	Weight	
ATOMIC ACCESSORIES, INC., 811 West Merrick Road, Valley Stream, N.Y., U.S.A.									
Slow neutron monitor (Thermal)	SN–87	Portable				Battery	9½ in×5 in×8½ in	7 lb	$410·00
Fast neutron monitor	FNS–113	Portable				Battery	10 in×4¾ in×5¾ in	6 lb	$1 195·00
BURNDEPT, LTD., Erith, Kent.									
Fast neutron monitor	1407C	Portable—hermetically sealed case		Linear 0–4 counts/s 0–40 0–400		Battery	16 in×10 in×5⅜ in	17½ lb	£250 approx.
EBERLINE INSTRUMENT CORP., P.O. Box 279 Santa Fe, New Mexico, U.S.A.									
Portable neutron counter	PNC–1								$725
Fast neutron counter	FN–1A								$725
EKCO ELECTRONICS, LTD., Ekco Works, Southend-on-Sea, Essex.									
Slow neutron survey meter	N578B	Portable		Linear		5 dry cells	9½ in×4⅞ in×8½ in	6¾ lb	
GENERAL RADIOLOGICAL, LTD., County Building, Honeypot Lane, Stanmore, Middx.									
Fast neutron monitor	NE 046	Portable	Earphones optional	Linear	60 hours continuous operation	Mallory cells, Type RM–12R	16 in×6 in×10 in	10 lb	£255
WM. B. JOHNSON AND ASSOCIATES, INC., P.O. Box 415, Mountain Lakes, New Jersey, U.S.A.									
Survey meter	FNS–3	Portable			5 mA	Dry cells	12 in	5 lb	$495·00
NUCLEAR CORP. OF AMERICA, Instrument and Control Division, 2 Richwood Place, Denville, New Jersey, U.S.A.									
Fast neutron, proton recoil tissue equivalent response	E–1D	Portable		Linear	6 flashlight cells		10 in×5 in×6 in	7 lb	$1 195
NUCLEAR ENTERPRISES (G.B.), LTD., Sighthill, Edinburgh 11, Scotland.									
Neutron monitor probes (transistorized)	NE 5551 NE 5561 EXP 611 EXP 612	Cylindrical containers							
Transistorized radiation meter	See α, β, γ monitors								
Transcint	963-TF	Kidney-shaped box		Linear		6V battery	7½ in×9 in×3 in	5 lb	£155
Transcint	963-TS	Kidney-shaped box		Linear		6V battery	7½ in×9 in×3 in	5 lb	
PLESSEY NUCLEONICS, LTD., Weedon Road, Northampton.									
Neutron/γ monitor	2NRM	Portable		Linear	70 mA	22V–16 Mallory cells type RM–4R	Indicator 12 in×8 in×7 in	11 lb+probes (3½–7 lb)	

NEUTRON MONITORS (SPECIFICATIONS)

Model	Detectors					Neutrons		Ranges	Energy Dependency	γ discrimination	Accuracy	Response time
	Counter Tube	Ion chamber		Scintillation counter		Fast	Thermal					
		Material	Volume	P-M tube	Phosphor							
ATOMIC ACCESSORIES, INC., 811 West Merrick Road, Valley Stream, N.Y., U.S.A.												
SN–87		Natural boron						0–15 m-rem/h 0–150 m-rem/h		80–1		
FNS–113		Methane Argon						0–5, 50, 500 /h m-rep plus integ.	0·2 to 14 MeV	γ background is effectively eliminated	±20%	
BURNDEPT, Erith, Kent.												
1407 C	Proton recoil chamber (proportional) BF_3					0·15 to 15 MeV		0–4 0–40 0–400 counts/s	0·7 cps/mpl	To radium γs<14 counts/min when 1 mC radium 1 cm from side of counter. To slow neutrons 1 counts/s per 100 mpl	±20%	
EKCO ELECTRONICS, LTD., EKCO Works, Southend-on-Sea, Essex.												
N578B		Enriched boron lined, 1 mg/cm²	235 cm³					0–3, 0–30, 0–300 m-rem/h	0·025 eV–30 eV approx.	300 : 1 against γ doserate	±10%	1s
FRANKLIN SYSTEMS INC., 2734 Hillsboro Road, West Palm Beach, Florida, U.S.A.												
MOD 15				EMI 9536	Plastic				>0·2 MeV	Fair to good	±5% nom.	1s
GENERAL RADIOLOGICAL, LTD., County Building, Honeypot Lane, Stanmore, Middx.												
NE 046	FN 2/3					0·15 to 15 MeV		0–4, 0–40, 0–400 counts/s	±20%	Sensitivity to slow neutrons and γ radiation negligible	10%	10s
WM. B. JOHNSON AND ASSOCIATES, INC., P.O. Box 415, Mountain Lakes, New Jersey, U.S.A.												
FNS–3	6292				ZnS			0·0–6 000 counts/min		5r γ	±20%	10s
NUCLEAR CORPORATION OF AMERICA, Instrument and Control Division, 2 Richwood Place, Denville, New Jersey, U.S.A.												
E-1D	Proton recoil					0·2–14 MeV		5, 50, 500 m-rep/h plus ·05 integrate range	Follow first collision tissue dose curve	60 mr/h	±20%	5s
NUCLEAR ENTERPRISES (G.B.), LTD., Sighthill, Edinburgh 11, Scotland.												
NE 5551				EMI 9584	Stilbene, NE 213 liquid scintillator, NE 150 plastic scintillator 2 in dia., up to 5 in long NE 451, Zn S/H up to 5 in dia.							
NE 5561				EMI 9584								
EXP 611 EXP 612				EMI up to 5 in dia.	NE 401, ZnS/boron polyester up to 5 in dia.							
Transistorized radiation meter					Zn S/H	3–3×10⁴ m-rep/h log						10s
					Zn S/B		1–10⁴ n/cm²s log					10s
963–TF (Fast)					Zn S/H	10³, 10⁴, 10⁵ counts/min						10s
963–TS (Thermal)					Zn S/B		10³, 10⁴, 10⁵, counts/min					10s
PLESSEY NUCLEONICS, LTD., Weedon Road, Northampton.												
2 NRM: Fast neutron probe				9578U	Modified Hornyuk type phosphor	0–300 m-rem/h in 4 ranges		0 to 1 0 to 3 0 to 30 0 to 300 m-rem/h	Linear to 10 MeV	Measurement may be made in the presence of radiation of 100 times the equivalent dose rate (up to a maximum of 300 mr/h)	≃25%	
2 NRM: thermal neutron probe				6097G	Enriched boron zinc sulphide		0 to 30 m-rem/h in 6 ranges	0 to 0·03 0 to 0·1 0 to 0·3 0 to 1 0 to 3 0 to 30 m-rem/h	Linear	Measurement may be made on the 0 to 1 and the 0 to 3 ranges in the presence of γ radiation of 100 times the equivalent dose rate	≃25%	

α, β, γ MONITORS (GENERAL)

General description	Model	Mounting	Indicator				Power		Size		Price
			Audible		Meter		Consumption	Supply	Linear dim.	Weight	
			Type	Preset	Linear/log	Trip					
A.E.I., LTD., Instrumentation Division, P.O. Box One, Harlow, Essex.											
Linear γ monitor	GM1	Bracket		External	Linear 0–1 r/h 4 ranges	Alarm and instr. failure	33 VA	100/125 V 200/250 V	9 in × 9¾ in × 9¾ in + ion chamber 20 in × 7½ in	53 lb	£335
Log γ monitor	GM2	Bracket		External	Log 0–10 r/h	2 × alarms instr. failure	33 VA	100/125 V 200/250 V	9 in × 9¾ in 9¾ in + ion chamber 20 in × 7½ in	53 lb	£355
Dosimeter	Victro-meter				Linear gratic-ule electro-meter		Nominal	200/250 V	9½ in × 8 in × 5½ in	14 lb	£230
Dosimeter	Cad. Sulphide				Linear		Nominal	200–250 V	Monitor 8 in × 6 in × 3 in. Probe: 4·5 mm dia.	20 lb	£135
AIRMEC, LTD., High Wycombe, Bucks.											
Radiation monitor	255	Portable	Loudspeaker and 'phone jack		Linear; also electro-magnetic counter		60 mA	Internal 12 V battery or external accumulator	12 in long, 5½ in wide, 8½ in deep	16 lb	£90–£21[illegible] according to probes and acces-sories required
Radiation monitor	1021 B	Bench type	Loudspeaker		Linear		90 VA	200–250 V 50 c/s mains supply	18 in wide, 11½ in deep, 11 in high	30 lb	£120–£145 according to probes required
ATOMIC ACCESSORIES, INC., 811 West Merrick Road, Valley Stream, New York, U.S.A.											
β γ survey meter	SM–131	Portable			Linear; 1·0, 10, 100 mr/h		250 h life	Size "D" cell	7½ in × 3½ in × 3½ in	4½ lb	$230·00
α β γ survey meter	SM–136	Portable			Linear; 1·0, 10, 100 mr/h		250 h life	Size "D" cell	7½ in × 3½ in × 3½ in	4½ lb	$280·00
Tritium monitor	TSM–91	Portable, bench			Linear; 0–10^3, 10^3, 10^4, 10^5 μ c of H^3/cm^3 of air			115 a.c.	11 in × 9 in × 8 in	12 lb	$595·00
α survey meter	ASM–94	Portable			Linear; 0–500, 2 500, 12 500 c/s α			Battery operated	6½ in × 8½ in × 7⅞ in	7½ lb	$395·00
ATOMIUM CORPORATION, 940 Main Street, Waltham 54, Mass., U.S.A.											
Low level γ detector	GD–1	Mobile (castors)	(Includes battery operated linear transistor pre-amplifier for use with any counting or spectrometer electronics)				+ H.V.		22 in wide, 37 in long, 38 in high	1 400 lb	$3 000·00–$6 000·00
BALDWIN INSTRUMENT CO., LTD., Lowfield Street, Dartford, Kent.											
Ionex		Console (trolley)			Linear		100 W	220 V a.c.	39 in × 22 in × 14 in	130 lb	£595
BENDIX ERICSSON U.K., LTD., High Church Street, New Basford, Nottingham.											
Miniature transistor-ized radiation monitor	125A	Portable	Miniature earphone		Linear; moving coil 0–50 mA		3 mA	3 × pen torch dry batteries	7½ in × 3½ in × 1¾ in	1½ lb	£42.10.0
As above, modified for intrinsic safety	125B	Portable	Miniature earphone		Linear; moving coil 0–50 mA		3 mA	3 × pen torch dry batteries	7½ in × 3½ in × 1¾ in	1½ lb	£48.0.0
General purpose α β γ instrument	145B	Portable	Headphones		Linear; moving coil 0–1 mA		20 mA	4 Mallory cells	3¾ in × 11¾ in × 10¼ in	101 lb	£210.0.0
High sensitivity instrument for geological surveying	1368A	Portable	Headphones		Linear; moving coil 0–1 mA		8 mA	3 × 1·5 V	11½ in × 3¾ in × 7 in	8½ lb	£136.0.0
General purpose scintillation head for research and training	214A	Bench type					100 μA at 1 kV	From associated equipment	12 in × 3 in dia.	8 lb	£95.0.0
BURNDEPT, LTD., Erith, Kent.											
Radiation monitor ratemeter	BN110	Portable case	Loudspeaker		Linear		100 W	100–125 V, 200–250 V, 50 V, 50 c/s mains conversion kit available	19½ in × 13¼ in × 13 in	35 lb	£150 approx.
EMI ELECTRONICS, LTD., Instrument Division, Blyth Road, Hayes, Middx.											
Portable contamination monitor	Type 1	Bench	Loudspeaker and head-phone		Log, scale at 0–5 000			Battery or 90–130 V, 200–240 V	8½ in × 11½ in × 8 in	11 lb	£250
EBERLINE INSTRUMENT CORPORATION, P.O. Box 279, Santa Fé, New Mexico, U.S.A.											
α counter	PAC–IS	Portable									$750
α counter	PAC–ISA	Portable									$625
β γ survey instrument	E–500–A										$400
β γ survey instrument	E–500–B										$550
γ doseratemeter	GADORA–1										$490
Air prop α counter	PAC–1–A										$450
Gas prop α counter	PAC–3–G										$571

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α, β, γ MONITORS (SPECIFICATIONS)

Model	Detectors			α Measurement			β Measurement			γ Measurement		Accuracy	Response time
	G-M tube	Ion chamber	Scintillation counter	Window mg/cm²	Window Area	Scale ranges	Window mg/cm²	Window Area	Scale ranges	Ranges	Energy dependence		
AEI, LTD., Instrumentation Division, P.O. Box One, Harlow, Essex.													
GM1		12 atm Argon 8 atm Air 4·7 l								0–100, –250, –500, –1 000 mr/h	100 keV	±3% FSD	5s
GM2		12 atm Argon 8 atm Air 4·7 l								0–10 r/h	100 keV	−0·45% +2·24% indicated	8s
Victrometer		Air 1 cm³								0–25, –100, –250 mr/h	50–500 keV	±2%	
Cs		Cadmium sulphide crystal								0–5, –50, –500 r/h	0·5–2·0 MeV	±5%	
AIRMEC, LTD., High Wycombe, Bucks.													
Radiation monitor 255 Internal geiger	G10H		27 MI with ZnS				30/35	10 in² surface	0–5, –50, –500, –5 000 counts/s		>0·1 MeV	Approx. 5%	Approx. 10s on 0–5, –50 ranges
β γ probe	B12H						1·5/2·5	1·5 in²			>0·5 MeV		
End window probe	EW3H			1	5 in²	0–5, –50, –500,	15	5 ml		0–5, –50, –500,			Approx. 1s on 0–500, –5 000 ranges
Liquid sample probe	M2H												
α probe						–5 000 counts/s				–5 000, counts/s			
Radiation monitor 1021			931A with ZnS										
βγ probe	B12			1	5 in²		30/35	10 in² surface			>0·5 MeV		
α probe													
BENDIX ERICSSON, U.K., LTD., High Church Street, New Basford, Nottingham.													
145B	1×CV 494		6097C with ZnS	12	3½ in²	0–10, 100, 1 000 counts/s	15	12 in²	0–10, 100, 1 000 counts/s	0–10, 100, 1 000	40 keV	±5%	2·5s
1368A	3×G24 HA									0–0·05, 0·25, 1·0, 5.0 25·0 mr/h		2% and 10%	0·2, 1, 1·5, 5, 15 and 20s
214A			BMS 1123/C with plastic NE101	3	1 in²		10	1 in²				1%	
125A and 125B	B10Hb									0–0·5 mr/h 0–5 mr/h	40 keV	±5%	1s
BURNDEPT., LTD., Erith, Kent.													
BN110	B12		(α probe) VMP/11/44 with ZnS	1	9½ in²	0–5, 50, 500,5 000	30/35	5×1½ in	0–5, –50, –500, –5 000			±2% FSD	Pulse amplifier ±3 db 2·5 kc/s 1·5 mc/s
EMI ELECTRONICS, LTD., Instrument Division, Blyth Road, Hayes, Middx.													
Dual probe DP.2			EMI 9524H with dual ZnS and plastic	>1·1	49 cm²	0–5 000 on a 5 in log scale	1·1	49 cm²	As for α	As for α		5% (electronic)	
α probe AP.2			EMI 9524H with ZnS	>1·1	49 cm²								
α probe AP.3			EMI 9 600 with AnS	>1·1	100 cm²								
β probe BP.3	B12H EW3H						30/35 1·5/2·5						
γ probe GP.2			EMI 9524H with NaI (Tl)										
All used with portable contamination monitor type 1.													
EKCO ELECTRONICS, LTD., EKCO Works, Southend-on-Sea, Essex.													
Radiation monitor N5968		Fibre glass matrix/ impr. poly/resin 880 cm³					3	200 cm³	0–3, –30, –300 mr/h		±10% from 10 keV to 3 MeV	±10%	7s
β/γ survey meter N555		Graphite loaded phenolic material 380 cm³							0–15, –150, –1 500 mr/h			±10%	6s
N645 with N674/N665			EMI 9524B with NaI (Tl)							0–10, 0–100, 0–1 000 counts/s		±5%	4, 8, 20s
N645 with N674/N646			EMI 9524B with ZnS	1·5	16 in²	0–10, 0–100, 0–1 000 counts/s						±5%	4, 8, 20s
N645 with N675	B12						50		0–10, 0–100, 0–1 000 counts/s			±5%	4, 8, 20s
N645 with N647	EW2e						7	10 cm²	0–10, 100, 1 000 counts/s			±5%	4, 8, 20s

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α, β, γ MONITORS (GENERAL)

General description	Model	Mounting	Indicator: Audible: Type	Indicator: Audible: Preset	Indicator: Meter: Linear/log	Indicator: Meter: Trip	Power: Consumption	Power: Supply	Size: Linear dim.	Size: Weight	Price
EKCO ELECTRONICS, LTD., Ekco Works, Southend-on-Sea, Essex.											
Radiation monitor	N596B	Portable			Linear			6 dry cells	10½ in high, ×6½ in×9 in long	6 lb	£75
β γ survey meter	N555	Portable			Linear			5 dry cells	8¾ in×9½ in ×4¾ in	6½ lb	£95
Field ratemeter with N674 scintillation counter, N665 γ head, N675 β head, N646 α head, N647 β head	N645	Portable			Linear			6 U2 cells	8 in×6½ in ×4½ in	7 lb	£110 (N674) £60 (N665) £20 (N675) £18.10.0 (N646) £20 (N647) £27.10.0
ELLIOTT NUCLEONICS, LTD., Century Works, Lewisham, London, S.E.13.											
Elliott β γ ground contamination monitor	ND 561	Permanently installed detectors with remote recording	Alarm contacts available	Adjustable	Linear or log	Adjustable		100/110 or 200/250 V, 50 c/s a.c.			Not fixed
Air monitor	1900	Wall or panel, with ionization chamber remote if required	Alarm contacts available	Adjustable	Linear or log	Adjustable		100/110 or 200/250 V, 50 c/s a.c.			Not fixed
FRANKLIN SYSTEMS, INC., 2734 Hillsboro Road, West Palm Beach, Florida, U.S.A.											
Portable	15–2	Portable			Linear	Option	5 W	Batteries	16 in×11 in ×9½ in	33 lb	
Medical	15–5	Bench			Linear	Option	5 W	140 V a.c.	6 in×8 in ×8 in	23 lb	
GENERAL ELECTRIC CO., ATOMIC POWER EQUIP. DEPT., 2151 S. First Street, San José, California, U.S.A.											
Area monitor	105X893	Relay rack	Edwards Cat. 374, horn	Preset	Log	Electronic	50 W	50/60 c/s, 110 V a.c.	19 in×8¾ in ×16 in	20 lb	$3 000–6 000 for 6 channels
GENERAL RADIOLOGICAL, LTD., County Building, Honeypot Lane, Stanmore, Middx.											
α floor probe	NE 060	Mobile			To ratemeter		100 mW	2 000 V from ratemeter	19 in×8½ in ×9¾ in+ handle	27 lb	£115
β γ floor probe	NE 061	Mobile			To ratemeter		100 mW	1 000 V from ratemeter	12½ in×19 in×15 in	44 lb	£83.10.0
γ monitor (installed)	NE 147	Wall			Log	2 variable 1 normally 10 mr/h	40 W	230 V	10½ in×19 in×15 in	44 lb	£304
Doseratemeter	NE 204	Portable			Log		24 h	2 U2 batteries	7¾ in×2½ in ×6 in	4 lb	£70
Scintillation monitor	NE 148	Portable			Log		600 h	2 U2 batteries	8¾ in×2¾ in ×5¾ in	4 lb	£224
ISOTOPE DEVELOPMENTS, LTD., Bath Road, Beenham, Reading, Berks.											
Portable transistorized γ survey instrument	1413A	Portable	Headphone	Continuous	Linear			3 U2 batteries	12 in×7 in ×4 in	11¾ lb	£283
Transistorized tritium gas monitor		Portable			Linear			Batteries	21½ in×10 in×7⅞ in		Not fixed
WILLIAM B. JOHNSON AND ASSOCIATES, INC., P.O. Box 415, Mountain Lakes, New Jersey, U.S.A.											
Portal monitor	IRL	Wall and portal		Preset	Linear, high level power		250 W	115 V, 50 or 60 c/s	6 ft high, 19 in wide	400 lb	$1 800
LABGEAR, LTD., Cromwell Road, Cambridge.											
γ monitor for hot cell operator protection	D 4125	19 in rack	Bell and flashing red lamp	Variable	6 decade log	Relay	50 W	110 V, 200/250 V, 50 c/s	19 in×8¾ in ×10½ in deep	32½ lb	£280
Health tolerance monitor	D 4121	Portable			Linear; 0–100 mpl's		1·5 W	210/240 V, 50 c/s	7 in×4½ in ×5 in deep	4½ lb	£36
A. M. LOCK AND CO., LTD., Prudential Buildings, 79 Union Street, Oldham, Lancs.											
Simcar radiation switch	RS3	Wall	Alarm	Preset			330 mW	230 V or 110 V, 50 c/s	13 in×9 in ×4 in		£70–£100
MARCONI INSTRUMENTS, LTD., Longacres, St. Albans, Herts.											
γ radiation monitor	TF 1299	Floor or wall	Bell	Preset	Log/log	Trip	7 W	200/250, 100/150 V a.c.	25 in high, 12 in wide	44 lb	£420
NUCLEAR-CHICAGO CORP., 333 E. Howard Ave, Des Plaines, Ill., U.S.A.											
Portable	2612 M				Linear			Battery	10 in×4⅜ in ×5⅜ in	10 lb	
	2612 P				Linear			Battery	10 in×4⅜ in ×5⅜ in	10 lb	
	2586 S				Linear			Battery	3⅛ in×8⅞ in ×13 in	4 lb	
	2586 P				Linear			Battery	3⅛ in×8⅞ in ×13 in	4 lb	

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α, β, γ MONITORS (SPECIFICATIONS)

Model	Detectors			α Measurement			β Measurement			γ Measurement		Accuracy	Response time (secs.)
	G-M tube	Ion chamber	Scintillation counter	Window mg/cm²	Window Area	Scale ranges	Window mg/cm²	Window Area	Scale ranges	Ranges	Energy dependence		
ELLIOTT NUCLEONICS, LTD., Century Works, Lewisham, London, S.E.13.													
ND561	Standard												
ND 1900		Ion chamber used filling of which is chosen to suit range of measurement.											
FRANKLIN SYSTEMS, INC., 2734 Hillsboro Road, West Palm Beach, Florida, U.S.A.													
15–2			EMI 9536 with plastic				20	7 in sphere		5:— 10^3–10^7 c/min		±5%	1s
15–5			EMI 9536 with plastic				20	6 in cylinder		5:— 10^3–10^7 c/min		±5%	1s
GENERAL ELECTRIC CO., Atomic Power Equip. Dept., 2151 S. First Street, San Jose, California, U.S.A.													
105X893			6655A with terphenyl							·01–1 000 mr/h		±10% of output current	10s at 1 mr/h
GENERAL RADIOLOGICAL, LTD., County Building, Honeypot Lane, Stanmore, Middx.													
NE060			EMI 6097C with ZnS on Perspex	1·0	8 in×8 in	Depends on rate-meter							Depends on ratemeter
NE061	B12									From background to limit of ratemeter			Depends on ratemeter
NE147		Gen. Rad. NE006 330 cm³								1–10^3 mr/h		±15%	Varies with reading
NE204	Miniature halogen quenched									0–10 000 mr/h	±40%	±20%	2s
NE148			EMI 9524B with 105g NaI							0–3 000 0–300 0–30 μr/h	20% (0·5–5 MeV)	±10%	3s
ISOTOPE DEVELOPMENTS, LTD., Bath Road, Beenham, Reading, Berks.													
1413A			6097B with 1½ in×1 in NaI(Tl)							0–1·5, –0·3, –0·06, –0·075 mr/h	Calibr. for natural radium	20% 10% 10% 10%	0·2 s 0·2s 0·6s 2·2s
Tritium Monitor		2·2 l					Gas flow rate 8l/min		50, 150, 1 500, 15 000 μμc of HTO	3 electro-deion chambers for γ compensation		20%	30s
LABGEAR, LTD., Cromwell Road, Cambridge.													
D4125		Al air wall 300 cm³								1–1 000 mr or 10–10 000 mr	Flat 300 keV to 2 MeV	±10% ±20%	2–4s
D4121	HC4 (20th Cent.) MX119 (Mullard)									0–100 mpl's	Flat 800 keV to 1·5 MeV	FSD ±1%	0–2s
A. M. LOCK AND CO., LTD., Prudential Buildings, 79 Union Street, Oldham, Lancs.													
RS3	MX120									0·1 to 5·0 mr/h	Above 0·1 MeV γ	2%	2s
MARCONI INSTRUMENTS, LTD., Longacres, St. Albans, Herts.													
TF1299		Steel/Al 4·7 l								0·1 to 100 mr/h	Flat down to 0·2 MeV	±20%	
NUCLEAR-CHICAGO CORP., 333 E. Howard Ave., Des Plaines, Ill., U.S.A.													
2612M	√						35					±10%	Varies with range
2612P	√			1·4–2	0·8 in²	600, 6 000, 60 000 c/min	1·4–2	0·8 in²	600, 6 000, 60 000 c/min	600, 6 000, 60 000 c/min			
2586S		Plastic 500 cm³					0·7	4·72 in²	25, 250, 2 500 mr	25, 250, 2 500 mr/h		±10%	
2586T		Plastic 5 cm³					0·7	0·372 in²	2·5, 25, 250 r	2·5, 25, 250 r/h		±10%	
NUCLEAR CORPORATION OF AMERICA, Instrument and Control Division, 2 Richwood Place, Denville, New Jersey, U.S.A.													
CS–40A		Plastic 500 cm³					75	3⅛ in dia. ×4 in		5, 50, 500, 5 000, 50 000 mr/h	+15% 0·2 to 3 MeV	20%	3–10s
D–6		Rubber hydro-chloride 100 cm³		0·6	40 cm²	500, 2 500, 12 500 c/min						20%	5s
CS–145	2 tubes						3·5	⅛ in dia.		5, 50, 500 mr/h, 5, 50, 500 r/h	Flat to 15% 80 keV		

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α, β, γ MONITORS (GENERAL)

General description	Model	Mounting	Indicator				Power		Size		Price
			Audible		Meter		Consumption	Supply	Linear dim.	Weight	
			Type	Preset	Linear/log	Trip					
NUCLEAR CORPORATION OF AMERICA, Instrument and Control Division, 2 Richwood Place, Denville, New Jersey, U.S.A.											
β γ	CS–40A	Portable			Linear		2 batteries		14 in×4 in ×4 in	7 lb	$330
α	D–6	Portable			Linear		Batteries		6 in×8 in ×7 in	7½ lb	$395
β γ	CS–145	Portable			Linear		2 batteries		8 in×3 in ×5 in	8 lb	$650
NUCLEAR ENTERPRISES (G.B.), LTD., Sighthill, Edinburgh 11, Scotland.											
Radio Iodine monitor (fully transistorized)	NE 8421	Portable			(4 meters) Linear		1 A(approx.)	12 V d.c.		112 lb	
Plutonium monitor (fully transistorized)	NE 8431	Portable, shoulder carried kidney shaped box with probe unit attached by cable			Linear		6 V d.c. battery		7½ in×9 in ×3 in	10 lb	
Transistorized radiation meter		Rectangular box (portable)			Log 4 decader			16 V battery	2½ in×3½ in ×7½ in	2½ lb	£155
	963TG	Kidney shaped box with gun			Linear			6 V battery	7½ in×9 in ×3 in	5 lb	£155
	1001 1001B (A) 1001B (B)	Kidney shaped box with gun			Linear			6 V battery	12½ in×9 in ×3 in	8 lb	£245
Whole human body radiation monitors	8101A										£6 000 approx.
	8102A										£6 700 approx.
	8102B										£8 200 approx.
Low level counting facility	810 5										
NUMEC, NUCLEAR METALS AND EQUIPMENT CORP., Apollo, Pa., U.S.A.											
Sentron	3S	Shelf and wall cabinets	Horns	Variable	Linear	Variable	Dependent on number of channels	115 V a.c. 60 c/s	23 in×14½ in×9 in up	40 lb up	Varies with number of channels and accessories
PANAK EQUIPMENT, LTD., Holmethorpe Industrial Estate, Redhill, Surrey.											
General laboratory contamination and assay monitor	5054	Bench	Speaker (switched)		Linear		75 W	Mains	15 in×10 in ×10 in	32 lb	£87.10.0
γ radiation monitor	TR 56	Hand	Headphones		Non-linear		400 h	Battery, 2× U2 type 1·5 V cells	7⅜ in×2½ in ×5½ in	3½ lb	£49.10.0
N.V. PHILIPS' GLOEILAMPENFABRIEKEN, Scientific Equipment Dept., Eindhoven, Netherlands.											
Portable monitors	PW 4012	Portable	Earphone		Linear			Battery	80×280×200 mm	1·8 kg	With batteries
	PW 4014	Portable	Earphone		Linear			Battery	180×100×47 mm	0·6 kg	
	PW 4015	Portable	Earphone		Linear			Battery	173×108×165 mm	1·6 kg	
Room alarm	PW 4044	Wall or bench			Log	1 cont. adjust.		110–250 V 50/60 c/s	230×230×125 mm	4 kg	
Four channel	PW 4046	19 in rack			Log	1 per channel cont. adjust.		110–250 V 50/60 c/s	480×266×350 mm	19·5 kg	
PLESSEY NUCLEONICS, LIMITED, Weedon Road, Northampton.											
Selective low energy γ monitor (single-channel pulse analyser)	PNI 1080	Portable			Quasi-log		15 W	50, 110 or 240 V, 50 c/s; or 12 V d.c.	Indicator: 9½ in×6½ in ×6 in	13 lb +probe	
Contamination Monitor	PNI 1045A	Portable			Quasi-log		Using an external 12 V supply the quiescent current is 40 mA approx., and the register drive draws 600 mA pulses	From internal battery or external 12 V d.c. supply	Indicator: 9 in×6 in ×6 in	8 lb +probe	
Background monitor	PNI 1072	Portable			Quasi-log		Battery life 400 h	9 V dry battery	Indicator: 9 in×6 in ×6 in	8 lb	
Contamination monitor	PNI 1065	Portable			Quasi-log		15 W	110 or 200/250 V 50 c/s; or 12 V d.c.	Indicator: 9½ in×6½ in ×6 in	10 lb +probe	
Selective γ monitor	PNI 1118	Portable			Quasi-log		15 W	50, 110 or 240V, 50 c/s; or 12 V d.c.	Indicator: 9½ in×6½ in ×6 in	13 lb +probe	
n/γ monitor (see also under neutron monitors)	2 NMR	Portable			Linear		70 mA	22 V–16 Mallory cells type RM4–R	Indicator: 12 in×8 in ×7 in	11 lb +probe	

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α, β, γ MONITORS (SPECIFICATIONS)

Model	Detectors			α Measurement			β Measurement			γ Measurement		Accuracy	Response time (secs.)
	G-M tube	Ion chamber	Scintillation counter	Window mg/cm²	Window Area	Scale ranges	Window mg/cm²	Window Area	Scale ranges	Ranges	Energy dependence		
NUCLEAR ENTERPRISES (G.B.), LTD., Sighthill, Edinburgh 11, Scotland.													
NE8421			EMI 6097A with NaI (TI) ½ in dia. × 1 in deep							3, 10, 30, 100, 300, 1 000 counts/s			1, 3·3, 10, 45s
NE8431			EMI 9524A with NaI (TI) 1 in dia. × 1 in deep							10^2, 10^3, 10^4 counts/s		10%	1–10s
Transistorized radiation monitor			ZnS, Stilbene, NaI(TI)	·01	200 cm²	10^2–10^4 c/min	·01	4 cm²	10^2–10^4 c/min	10^2–10^4 c/min			10s for all
963TA			NaI (TI)							·02, ·2, 2 mr/h			
1001													
1001B(A)			ZnS	·01	12 cm²	10^3, 10^4, 10^5 c/min							
1001B(B)			Stilbene				·01	4 cm²	10^3, 10^4, 10^5 c/min				
8101A			Two 7 in dia. with Plastic scintillators 20 in × 10 in × 6½ in									Approx. 16%	
8102A			Four 5 in dia. with NaI (TI) 4½ in × 2 in									10%	
8102B			Four 5 in dia. with NaI (TI) 5 in × 4 in									10%	
8105			8 EMI 9530 with plastic scintillators 23½ in × 7 in × 12 in									K^{40}: 25% Cs^{137}: 22%	
NUMEC, NUCLEAR METALS AND EQUIPMENT CORP., Apollo, Pa., U.S.A.													
Sentron 3S	Infinite life									0–100 mr/h others available		±10%	200 ms
PANAX EQUIPMENT, LTD., Holmethorpe Industrial Estate, Redhill, Surrey.													
5054	All		EMI 6097, 9514, etc. with NaI, Anthracene Plastic, ZnS (Panax-USC assemblies)	0·6	3 in²	0–400, –2 000, –10 000, –40 000 c/min	2	6 in²	0–400, –2 000, –10 000, –40 000 c/min		10% 0·6–1·2 MeV	±2%	1–5–25s
TR56 range of monitors	Internal: MX120/01. External: MX108/01 or any 400V tube						2	114 mm²	0–5K, 0–25K, c/min	0–0·5, –5, –10, –50 mr/h		±10%	1 and 6s
N.V. PHILIPS' GLOEILAMPENFABRIEKEN, Scientific Equipment Dept., Eindhoven, Holland.													
PW 4012	18503									0–1, –10, –100 mr/h	Within 25% for 80–1 200 keV		
	18505						1·5	19·8 mm dia.	3				
PW 4014	18503 18504						2	9 mm dia.	2	0–3, –30, 0–60, –600 mr/h			
PW 4015	18503 18509						Any external probe			0–10, –100, –1 000 mr/h	Within 25% for 80–1 200 keV		
PW 4044	18520									0·01–10,	Within 25%		
PW 4046	18503 18509									0·25–50, 2·5–500 mr/h	for 80–1 200 keV		
PLESSEY NUCLEONICS, LTD., Weedon Road, Northampton.													
PNI 1080			9524B (selected) with NaI(TI)							10–60 keV (any one emission)	Linear	About ±10% but depends upon sample time, counting geometry, etc.	
PNI 1045A	EWG 5H or M2H						15	3 cm²	10–500 counts/s	30 counts/s	Dependent on characteristics of G.M. tube		
							17	5 ml samples		10 counts/s mr/h			
PNI 1072	Halogen quenched									0–3 mr/h			
PNI 1065 with lead castle	2B2 or 2B7						1·6–2·4	2 cm²	0–1 000 counts/s				
							7	2 cm²					
PNI 1065 with dual purpose castle	M2H or EWG5H						17	5 ml samples	0–1 000 counts/s	10 counts/s mr/h			
							15	3 cm²		30 counts/s mr/h			
PNI 1065 with hand probe	EWG5H						15	3 cm²	0–1 000 counts/s	30 counts/s mr/h			
PNI 1065 with γ probe	HC4								0–1 000 counts/s	6 counts/s μc/l rate-meter range			
										0–1 000 counts/s			
α and γ scintillation probes can be supplied for use with the 1065 monitor													

(Continued on page 297)

α β γ MONITORS (GENERAL)

General description	Model	Mounting	Indicator				Power		Size		Price
			Audible		Meter		Consumption	Supply	Linear dim.	Weight	
			Type	Preset	Linear/log	Trip					
Plessey Nucleonics (Contd.)											
Selective low energy γ monitor	PNI 1094	Portable			Quasi-log		Battery life approx. 100 h	Internal 9 V dry battery	Indicator: 7½ in × 4½ in × 4 in	4½ lb + probe	
Survey meter	1541A	Portable			Approx. log		13 mA	6 Mallory type RM12R 1·34 V mercury batteries	5½ in × 3 in × 5¼ in	4½ lb	
Contamination monitor	PNI 1125	Portable	Loudspeaker	Preset					7½ in × 5 in × 4 in	5½ lb	
RADIATRON, 7 Sheen Park, Richmond, Surrey.											
Pocket size dosimeter	PTW	Pocket	Buzzer	20, 30, 50 100, 500, 5 000 mr			Nil during measurement; 50 mA during signal	Accumulator Edison type	110 × 74·5 × 37·5 mm	350 g	£38.15.0+ £13.0.0 duty
THE REDCLIFFE RADIO AND ENGINEERING CO., LTD., Emery Road, Brislington, Bristol 4.											
γ area monitor	1641 C	Wall	Bell and 3 colour lamp unit	Preset	Linear	Trip	55 VA	200/250 V 50 c/s	7 in deep, 15 in wide, 18½ in high lamp unit: 6 in × 4 in × 13 in	25 lb lamp unit: 4 lb	
RESEARCH AND CONTROL INSTRUMENTS, LTD., 207-15 King's Cross Road, London, W.C.1.											
Philips	PW 4012	Portable	Earphone		Linear		22 mA	3 V battery	11 in × 8 in × 3½ in	4 lb	
	PW 4014	Portable	Earphone		Linear		12 mA	3 V battery	6½ in × 4 in × 1⅝ in	1 lb 5 oz	
	PW 4015	Portable			Linear						
	PW 4044	Wall	Optional		Linear	High and low adjustable		Mains	13 in × 9½ in × 5 in		
	PW 4166	Rack	Optional		Linear						
AB SCIENTA, P.O. Box 366, Göteborg 1, Sweden.											
γ Low intensity	IM–12	Portable			Linear		10·5 V, 35 mA	Battery 7 × 1·5 V	125 × 160 × 255 mm	4·2 kg	SwCr:1 060
γ High intensity	IM–21	Portable			Linear		4·5 V, 20 mA	Battery, 3 × 1·5 V	255 × 130 × 170 mm	2·3 kg	SwCr: 700
SELO—SOC. ELETTRONICA LOMBARDA, Via Monfalcone 12, Milan, Italy.											
	MRG310DT	Portable	Earphone		Linear		50 mA–6 V	Storage battery	7·5 × 17 × 18 cm	2·2 kg	
	MRI202	Portable			Linear			Batteries	8·5 × 18·5 × 18 cm	3·8 kg	
TRACERLAB, INC., 1601 Trapelo Road, Waltham 54, Mass., U.S.A.											
Area monitoring system, with up to 10 probes, alarm and rate-meter, central power supply and control	Probe: TA–6 Control and power: TA–1	Portable or on wall-brackets	Horn available; alarm lights on probe and control unit		Log, calibr. in mR/hr	On meters of central control					Dependent on number of stations and accessories
URANIUM INSTRUMENTS CO., P.O. Box 1191, Grand Junction, Colorado, U.S.A.											
Transistorised mine control or hole probing G–M counter	700 NM	Portable			Semi-log		0·282 W	5 "D" type flashlite cells	8 in × 4½ in × 3¾ in	4½ lb	$278
Accessories:											
"T" handle HD γ load probe	HT 700										
Deep hole and back hole γ probe	PSI 1 000										
Differential face scanner	VLS and VHE										
THE VICTOREEN INSTRUMENT CO., 5806 Hough Ave., Cleveland 3, Ohio, U.S.A.											
Thy AC II	489	All metal case	Earphone		Linear		100 h-battery life	4 "D" cells	8¾ in × 4½ in × 7 in	4 lb	$175
G–M survey meter	EP 271	All metal case			Linear		40 h-battery life	2 "D" cells	8½ in × 4 in × 5½ in	5½ lb	$450
Low energy survey meter	440	All metal case			Linear		100 h-battery life	4 "D" cells	10 in × 7½ in × 4 in	5½ lb	$595
γ dosimeter	592B	Fibreglass case			Linear		250 h-battery life	Batteries	10 in × 4¾ in × 7 in	4¾ lb	$325
Cutie Pie	740	Metal case, gun grip			Linear		200 h-battery life	Batteries	9 in × 11½ in × 3½ in	3½ lb	$295
Radgun	AGB–10KG-SR	Metal case, gun grip			Log		350 h-battery life	Batteries	4½ in dia. × 12¾ in long	4½ lb	$425
Radector	AGB–50B–SR	Metal case			Log		350 h-battery life	Batteries	5 in × 3½ in × 6 in	3½ lb	$295

α, β, γ MONITORS (SPECIFICATIONS)

Model	Detectors			α Measurement			β Measurement			γ Measurement		Accuracy	Response time (secs.)
	G-M tube	Ion chamber	Scintillation counter	Window mg/cm²	Area	Scale ranges	Window mg/cm²	Area	Scale ranges	Ranges	Energy dependence		
Plessey Nucleonics (Contd.)													
PNI 1118			9524B (selected) with NaI(Tl)							10 keV to 1·5 MeV	Linear		
2NRMn/γ probe			9514S with Anthracene							0–300 mrem/h in 5 ranges down to 0·1 mrem/h	0·1 to 6 MeV	—25%	
PNI 1094			9524 with NaI(Tl)							10–60 keV 0–100 counts/s	Linear	±10%	
Survey Meter 1541A		Al with an inner lining of conductive phenolic material 72 cm²								Over 3 decades to 500 r/h	Linear from 100 keV upwards	±20%	
PNI 1125	EWG5H						15	3 cm²	Pre-set for alarm at 3·4× 10⁴ dpm/g activity in food	Compensation from 2 mr/h to 50 mr/h by variable control		±20%	
RADIATRON, 7 Sheen Park, Richmond, Surrey.													
PTW		Al 13 cm³									80 keV–2 MeV	±10%	
THE REDCLIFFE RADIO AND ENGINEERING CO., LTD., Emery Road, Brislington, Bristol 4.													
1641 C		Al 3·5 l.								0–300 mr/h, 1st alarm level:— 30 mr/h, 2nd:— 285 mr/h		20%	2 s
RESEARCH AND CONTROL INSTRUMENTS, LTD., 207/15 King's Cross Road, London, W.C.1.													
PW 4012	18503									0–100 mr/h			
	18504						2–3						
	18505			1·5–2·0								<10% FSD	
PW 4014	18503									0–3, –30 mr/h		±5% FSD	
	18504												
	18509								0–10, –100,				
PW 4015	18503			1·5–2·0			1·5–2·0		–1 000 c/s	0–10, –100, –1 000 mr/h	80 keV–1·2 MeV	±10%	
	18509												
	18508												
RIGGS NUCLEONICS CORPORATION, 135 W. Magnolia Boulevard, Burbank, California, U.S.A.													
GA–3A system single channel		Pure argon gas 28 in³								80 keV–1·2 MeV	10%	10%	90% full scale <4 s depending on flux
AMS–11A system, multi-channel										10⁻⁶ r/h to 10³ r/h			
AB SCIENTA, P.O. Box 366, Goteborg 1, Sweden.													
IM–12	MX 115									5 mr/h 50 mr/h	>0·8 MeV	±10%	90%<3 s
IM–21		Plastic 200 cm³					22	33 cm²		0·2, 2, 20, 200 r/h	0·1–2 MeV	±10%	60%<3 s
SELO-SOC. ELETTRONICA LOMBARDA, Via Monfalcone 12, Milan, Italy.													
MRG 310DT	EW3H, B6H or G5H		ZnS	0·6	30 cm²		2·0	3 cm²	2, 20, 200, 2 000 IPS full scale	0·04, 0·4, 4·0, 40 mr/h full scale	Corr. factor 0·5÷2 for energies >20 keV	5%	
MRI 202		Al 500 ml								0·5, 5, 50, 500 r/h	±15% 150 keV–2 MeV	10%	
URANIUM INSTRUMENTS CO., P.O. Box 1191, Grand Junction, Colorado, U.S.A.													
700 NM	Halogen quenched						30		3	0–0·5, –5, –50 mr/h	>175 keV		
THE VICTOREEN INSTRUMENT CO., 5806 Hough Ave., Cleveland 3, Ohio, U.S.A.													
489				1·4–2·0	1 in dia.	0–80 000 c/min					±20% 80 keV–2 MeV	±10%	
EP–271				1·4–2·0	1 in dia.	0·5–500 mr/h							
440		Bakelite and mylar					1·0	3⅜ in dia.	0–300 mr/h		±15% 6·5 keV–1·2 MeV	±10%	
592B		Metal							0–1 000mr/h		±10% 50 keV–1·2 MeV	±10%	
740		Bakelite		1·0 mylar							±15% 40 keV–2 MeV	±10%	
AGB–10KG–SR		Metal					20 steel		0·01 mr/h–	10 000 r/h			

RADIOACTIVE DUST MONITORS

Model	Application	Continuous or batch	Method of sampling	Detector	Indicator	Ranges	Sensitivity α	Sensitivity β	Sensitivity γ	Response time	Weight	Price
CONSTRUCTIONS RADIOELECTRIQUES et ELECTRONIQUES DU CENTRE, (CRC), 19 rue Daguerre St. Etienne (Loire), France.												
EAR 620	Radioactive dust monitor	Continuous		Scintillator	Potentiometer recorder		2×10^{-6} μc/m³	3×10^{-5} μc/m³		Immediate	210 kg	19 000 NF
EBERLINE INSTRUMENT CORP., P.O. Box 279, Santa Fe, New Mexico, U.S.A.												
AM-12 AM-5C		Continuous	Filter	Scintillator	Meter, chart	Four					450 lb	$3 433 $13 000
GENERAL NUCLEAR CORP., 1203 S. Cypress, Fullerton, Cal., U.S.A.												
710	Air monitor	Continuous		Scintillator	Meter, chart, alarm	0–600 000 counts/min				1 min	400 lb	
701	Air monitor	Continuous		G–M tube	Meter, chart, alarm					30 min	400 lb	
WM. B. JOHNSON AND ASSOCIATES, INC., P.O. Box 415, Mountain Lakes, New Jersey, U.S.A.												
2144	Air particulate monitoring	Continuous	Moving filter tape	G–M tube	Linear count ratemeter	0–5 000 counts/min				5 s	1 500 lb	$3 000
2144S	Air particulate monitoring	Continuous	Moving filter	Scintillation counter	Linear count ratemeter	Five				5 s	3 000 lb	$3 000
NUCLEAR ENTERPRISES (G.B.), LTD., Sighthill, Edinburgh 11, Scotland.												
1020 and 1001A	Uranium mines	Batch	Air pump and filter	ZnS	Meter	1 000 10 000						£100 £245
Air impactor	Monitoring plutonium and other particles in atmosphere	Continuous	Impacting	ZnS	Meter	100 000 counts/min						£1 500
N. V. PHILIPS GLOEILAMPENFABRIEKEN, Eindhoven, Netherlands.												
111.510	Air-dust monitoring	Batch	Sample build-up with a continuous airflow	End window G–M detector window dia. 2 in	Logarithmic C–R meter and strip-chart recorder	0·1–100, 1–1 000, 10–10 000 counts/s						
RESEARCH AND CONTROL INSTRUMENTS, LTD., 207-15 King's Cross Road, London, W.C.1.												
	Area control	Continuous	Paper	Scintillation and G–M	Ratemeter (linear/log)	0·1–10 000 counts/s 0·5–50 000 counts/s				Variable 400–1 000 s		
SCHMIDT INSTRUMENT CO., P.O. Box 111, San Carlos, California, U.S.A.												
2–AP	Environmental monitoring; total exposure monitoring	Continuous with automatic flow control to 16 inHg vacuum	Fixed filter	Separate	As required (extra)						38 lb	$640
10–AP	Stack sampling; in-plant monitoring; low concentration measurements; remote weapons test monitoring	Continuous with automatic flow control to 16 inHg vacuum	Fixed or moving filter	As required (extra)	As required (extra)						200 lb	$1 390
SELO-SOC. ELETTRONICA LOMBARDA, Via Monfalcone 12, Milan, Italy.												
RA 202		Continuous	Filtering	G–M tube or scintillation counter	Meter and recorder	1–1 000 of max. sensitivity	$1·5\times10^{-2}$ μμc/m³	3×10^{-2} μμc/m³		Variable delay from 2–50 h	250 kg	
TRACERLAB. INC., 1601 Trapelo Road, Waltham 54, Mass., U.S.A.												
MAP–1A	Indication of radioactivity level of airborne particulate	Continuous	Moving filter tape	α, β or γ G–M and scintillation detectors can be used, up to 3 in one system	Ratemeter, electronic or trip alarm circuit, recorder; remote alarms possible		Po^{210} 1×10^{-12} μc/cm³	Pm^{147}: $1·5\times10^{-4}$ μc/cm³	Co^{60}: 8×10^{-12} μc/cm³	Immediate; dust deposited on filter in front of detector	600 lb approx.	From $4 800
MAP–5	Monitoring of radioactivity level of airborne particulate	Batch	Fixed filter: 2 in dia. HV–70	Scintillation detector	Ratemeter, alarm circuit	Graphs showing time versus concentration for count rate to reach 100 counts/min are available on request.					45 lb	$1 640
THE VICTOREEN INSTRUMENT CO., 5806 Hough Ave., Cleveland 3, Ohio, U.S.A.												
900–56A	Reactor and plant radioactive air particle monitoring	Continuous	Vacuum pump with moving capstan and continuous filter paper tape	G–M and/or scintillation	Meter readout and strip-chart recorder	10–10 000 000 counts/min					450 lb	$4 950
VITRO ELECTRONICS, Division of Vitro Corp. of America, 919 Jesup Blair Drive, Silver Spring, Maryland, U.S.A.												
APS–11A	Air-dust sampler, quantity or intensity of radioactive particles	Batch, readings can be made while in operation	Filtering and metering vol. of air passed in given period of time		Calibrated flow counter: 999·9 m³ or 9 999 ft³ total capacity resettable	16 800 l/h (16·8 ft³/h)				Varies with vol. of air being sampled	25 lb	$500

Radiation Damage in Ceramics

This article supplements the information contained in two previous discussions of the properties of ceramics by G. Arthur of Parsons Nuclear Research Centre. (*Nuclear Engineering*, April and June, 1961.)

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MATERIALS employed within the biological shield must be capable of withstanding large doses of radiation without serious changes in their mechanical properties. As the behaviour of a solid is governed by its crystal structure property changes will be produced by disarrangement of the crystal lattice. The importance of a study of radiation damage was first appreciated by Wigner[1] (c. 1939-45) although Des Cloizeaux and Damour[2] had noted as early as 1860 damage arising in some minerals containing radioactive impurities. In many cases the accumulation of damage in these materials is sufficient to completely destroy the long-range order of the crystal structure.

Mechanisms of Radiation Damage

The various types of radiation possible in pile are shown in Table 1. Energy of the order of 10^{18} eV is released during fission; the bulk of this is taken by the two fission fragments, with average energies of 95 and 61 MeV, the remainder being shared by the other fission products. The interaction of these species with the crystal lattice results in three main classes of damage.

(a) Ionization and electronic excitation

These are caused by all types of fission product.

(b) Transmutation damage

The conversion of an atom to a different atomic species by slow neutron capture and nuclear reaction.

(c) Knock-on damage

The removal of an atom from its normal lattice position by elastic collision with a fission fragment, fast neutron or α particle.

(a) **Ionization and electronic excitation**

This describes the removal or displacement to a higher energy level of the outer electrons of an atom by the passage ot fast particles or γ radiation through the lattice. Above a limiting energy, the limit varying with the type of particle, most of the energy of the incident particle is lost in causing ionization; fission fragments produce the most severe ionization. The electronic properties of non-metals are particularly sensitive to the displacement of electrons and have been extensively used in studies of radiation damage. Electrons stripped from atoms may be trapped at defects and so form colour centres—regions which show altered optical absorption characteristics which are distinguished by colour changes in the material. The provision by defects of extra charge traps or donors can cause changes of several orders of magnitude in the electrical conductivity of semi-conductors where the carrier concentration is normally very small.

TABLE 1
PILE RADIATION

Radiation	Description	Damage produced
Fast neutron (n_f) ..	Mass 1. Charge 0 Energy = 10^4 eV or more	Displacements; ionization
Slow neutron (n_s)	Mass 1. Charge 0 Energy = 0·025 eV or less	Transmutation; ionization
Alpha particle (α)	Mass 4. Charge 2	Displacements; nuclear reactions; ionization
Fission fragments	Fragments of fissioned atoms	Displacements and ionization (severe)
Electron (e) ..	Mass $\frac{1}{1837}$ Charge −1	Minor ionization
Gamma (γ) ..	Electromagnetic radiation of $\lambda = 10^{-7}$–10^{-11} cms	Ionization

Note: nvt = integrated neutron flux.
n = neutrons/cc in incident beam.
v = neutron velocity (cm/s).
t = exposure (s).

(b) **Transmutation damage**

Damage can also be caused by the substitution of the original species in the lattice with impurity atoms formed by the interaction of thermal neutrons with lattice atoms, e.g., the n,α reaction of B^{10} to give Li^7 and He^4. The production of gases in this fashion can cause abnormal swelling in plastic materials by the nucleation and growth of gas bubbles in internal pores, as for example at the interface of the fissile particle and matrix in a dispersion fuel; in brittle materials such build-up can cause fragmentation[3].

(c) **Knock-on damage**

Fission fragments, α-particles, fast neutrons, etc., can lose energy either by (a) inelastic collisions, causing ionization, or (b) elastic collisions when their energies have been sufficiently reduced. Displacement occurs if the energy transferred in elastic collision is greater than c. 25 eV. It can be shown that the bulk of the energy of the fission fragment is expended in ionization[4]. As the fission fragment is charged its collision cross-section is relatively large and displacements are produced very close together, forming a track of damage over a short range. These displaced atoms generally have sufficient energy to produce secondary displacements which, in turn, produce tertiary and further displacements of progressively diminishing energy, resulting in a spike of radiation damage consisting of vacant lattice sites and interstitial atoms. Fission fragment effects are confined to the fuel and its immediate vicinity as their range is only of the order of 10μm. The collision probability of a fast neutron is small and hence it is at relatively isolated points along its path that displacements are produced; secondary and further displacements can result, as in the case of the fission fragment. Fast neutron damage therefore consists of a number of isolated regions of disorder. Compared with the fission fragment a larger fraction of the energy of the neutron is available for producing displacements. The range of the neutron is such that most reactor structural components are subject to neutron fluxes.

Knock-on damage produces a variety of effects in irradiated materials. Density changes stem from the expansion produced by the introduction into the lattice of interstitial atoms. Changes in properties such as hardness and elastic moduli are caused by the disruption of the lattice. In metallic materials the displaced atoms pin dislocations and thus hinder deformation; in ceramics, where failure is normally in a brittle manner, radiation damage may assist in the formation and propagation of Griffiths cracks, so weakening the material. Since the whole effect of thermal conductivity in ceramics is by lattice conduction, defects produce a marked decrease in thermal conductivity by scattering the energy quanta travelling through the lattice.

Energy transfer between the incident particle and the atoms along its path generates thermal spikes—regions of intense heating along the path of the particle, particularly at the end of its range. It can be calculated[5] that in this region temperatures of more than 1 000°C affecting several thousand atoms may exist for 10^{-11} seconds; the rapid heating and quenching may assist processes such as diffusion and the introduction of metastable phases. Two examples of radiation-induced phase changes in ceramics have been reported. Barium titanate is transformed from the stable tetragonal form to the cubic structure[6] and natural zirconia transforms from monoclinic to cubic by exposure to fast neutrons. The cubic structure is the high temperature form in both cases, being stable above 120°C in the case of barium titanate and above 1 900°C for zirconia. It is suggested[7] that the barium titanate lattice relieves the stresses produced in the lattice by interstitials in the same manner as it accommodates thermal stresses, that is by phase change to the cubic form. The change in zirconia has been shown to result from fission fragment damage arising from fissionable impurities in the natural mineral[8]; pure synthetic zirconia is stable to fast neutron exposure. The phase change in this case is attributed to a fission spike mechanism with a quenching in of the high temperature form[8].

The rate of chemical reactions may also be affected by irradiation. At 350°C the oxidation rate of graphite by carbon dioxide is considerably higher than can be attributed solely to the effect of temperature. This effect is ascribed[9] to the production of a reactive species in the gas, e.g., atomic oxygen or ozone. The phase change from a metastable to a stable state, as in devitrification, can be classified as a rate process and has been observed to be accelerated by neutron irradiation. Since the oxidation resistance of SiC is due to the formation of a glassy layer of SiO_2 on the surface the effect of radiation on the reacting components will be of considerable interest, viz., the SiO_2 surface layer may be devitrified and in addition the rate of the forward reaction may be increased.

Recovery of Radiation Damage

A distorted lattice is thermodynamically unstable and on post-irradiation heating the physical properties tend to revert to their original values as lattice order is restored. Associated with the disorder there is energy stored in the lattice; in the case of graphite this energy can in certain circumstances be rapidly released on annealing and can cause an uncontrolled temperature rise. Silicon carbide also stores appreciable quantities of energy on irradiation. Usually, in addition to thermally activated recovery, some degree of recovery takes place in-pile; this radiation annealing is attributed to the occupation of vacancies by

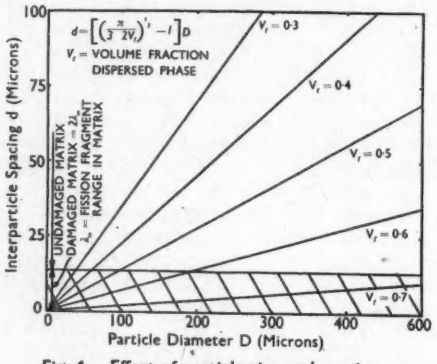

Fig. 1.—Effect of particle size and spacing on undamaged interparticle distance.[21]

Fig. 2.—Fission fragment damage in UO_2/s.s. dispersion. White *et al.*[21]

displaced atoms. The probability of this happening increases with exposure and the situation tends towards a saturation of damage. Thermal spike heating is not thought to have a significant effect in annealing. Changes in composition caused by transmutation and gross structure changes such as the formation of pores and cracks are not, of course, subject to recovery processes.

Radiation Sensitivity: Minimization of Damage

The ease of formation of lattice defects and their subsequent stability is governed by the bond type and crystal structure of the material. For ceramics there is a wide range of bond type from ionic, e.g., UO_2 through ionic/covalent to covalent, e.g., diamond, SiC. The hard metal carbides exhibit ionic/metallic bonding. An ionic bond is electrostatic and non-directional and a lattice with this type of bonding can accommodate considerable distortion without adverse effects. The most stable structures are generally those of closest packing and highest symmetry; for example, the good irradiation stability of UO_2 is related to its close-packed fluorite structure, and in contrast orthorhombic U_3O_8 is readily destroyed even at low doses. Covalent bonding is rigid and directional and is much less able to accommodate lattice distortion and radiation sensitivity will therefore increase with increasing covalent character. Layered lattices such as graphite and boron nitride show undesirable anisotropic expansion on irradiation.

The effects of radiation can therefore be minimized by using materials of ionic character of high symmetry. Materials that exhibit radiation-induced phase changes and those which transmute to a new atomic species should be avoided. Increased temperature of irradiation can in some cases be employed to reduce radiation damage by promoting annealing. Dispersion fuels can be employed to confine the effects of fission fragments to the immediate neighbourhood of the fissile phase. If the range of the fission fragment in the matrix material is known, control of the particle size of the fissile phase will ensure an optimum amount of undamaged matrix to provide the strength of the dispersion system (Figs. 1 and 2).

Property Changes in Ceramics

Bulk Fuels

For both stoichiometric and nonstoichiometric UO_2 there are no changes in the microstructure or dimensions for

burn-ups up to 25 000 MWd/t other than can be attributed to thermal effects. Micrographs of irradiated UO_2 (Fig. 3) show predominantly radial cracking which results from the application of a thermal gradient to the material; the cracked surfaces are held together by the can and the smaller cracks may subsequently re-sinter should the operating temperature be high enough. In stoichiometric UO_2 columnar grains are formed when the temperature of grain growth is reached and an axial hole is produced in the fuel rod in conditions where the central temperature has exceeded the melting point. Central hole formation in nonstoichiometric UO_2 is caused below the melting point by mass transfer of oxygen-rich material by evaporation with subsequent condensation and decomposition in a cooler section of the fuel element. The release of volatile fission products within the can, with the attendant danger of can rupture and the lowering of the thermal conductivity of the fuel/can gas gap, are important factors in fuel element design. Fission gas release is a diffusion controlled process, the amount released increasing with operating—sharply when recrystallization occurs and drastically if the melting point is exceeded—and decreasing as density increases for a specific type of UO_2. The release from non-stoichiometric UO_2 is markedly greater. For UO_2 of 95% theoretical density only 0·1% of the K^{85} produced was released at 1 600°C[10]; in contrast, Bain and Robertson[11] measured 0·1% fractional release from 87% T.D. UO_2 at 350°C and 20% release from $UO_{2\cdot15}$ of the same density and irradiation history.

Work by Robertson *et al*[12] on the irradiation of high density UO_2 has shown that above 700°C the in-pile thermal conductivity is similar to that for unirradiated UO_2 (Fig. 4). Below 700°C the values are lower and at 100°C are about 40% of the unirradiated value. The "effective" in-pile thermal conductivity of encapsulated UO_2 has been shown to be sensitive to variation of diametrical clearance[13, 14]. On elimination of the interface gap, Cohen's values were much nearer those for unirradiated UO_2 and it was concluded that for 95% T.D. UO_2 the in-pile thermal conductivity is unaffected by irradiation, at least above 500°C to a burn-up of 4×10^{19} fissions/c.c. The difference between the results of Robertson and of Cohen at low temperatures has been discussed by Ross[15] who has produced evidence to show that the thermal stability of damage is increased with increasing exposure; this is consistent with the fact that the exposures of Robertson were a factor of four greater than those in Cohen's work. It is unlikely that the value of the in-pile thermal conductivity up to the melting point will fall below 0·003 cal/cm s°C[16].

Arc-cast UC irradiated to a burn-up of 25 000 MWd/t and with an estimated central temperature of 1 100°C has shown good irradiation stability. A density decrease of 4% was noted[17] and metallographic examination revealed that, if present initially, UC_2 tended to go into solution on irradiation. Fission gas release was low and agreed with that predicted from a recoil mechanism up to 8 000 MWd/t. Estimates[18] of the in-pile thermal conductivity for arc-cast UC operating at 540-820°C show a 58% decrease relative to the initial thermal conductivity of 0·05-0·06 cal/cm s°C. The behaviour of the sintered material is inferior, cracking and a 10% fractional release having been observed[19] from sintered UC of $\rho=10{\cdot}5$ (76·8% T.D.) after an irradiation of 3 000 MWd/t at 650°C. The results obtained so far show that arc-cast UC behaves as well as UO_2 on irradiation.

Dispersion Fuels

The theory of dispersion fuels has been treated by Weber and Hirsch[20] and White *et al*[21] amongst others. These materials can be classified according to the matrix, which can be a metal, graphite, a ceramic oxide or a ceramic carbide.

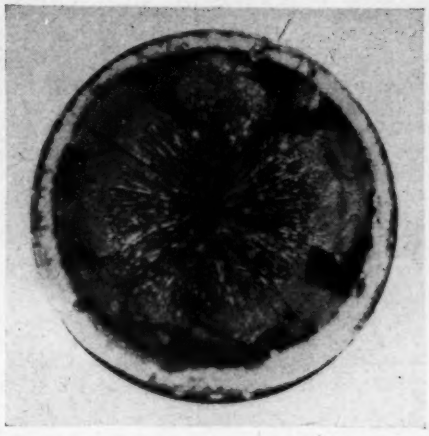

Fig. 3.—Irradiation damage in UO_2.
Eichenberg *et al*.[10]

As discussed by Williams[22] the low absorption cross-section metals beryllium, aluminium and magnesium are excluded from use as matrices in dispersion fuels intended for operation above 600°C. One of the most widely investigated dispersions for high temperature use has been UO_2 dispersed in austenitic stainless steel. Investigation of a series of 25w/o UO_2 specimens with oxide particle sizes in the range 44μm to 210μm showed that good dimensional stability had been achieved at burn-ups of 20-40% UO_2 and matrix temperatures of 650°C[23]. No volume change was noted for 90-95% dense material, a 1-2% volume increase being observed at 98% theoretical density. Porosity can thus minimize volume increases by providing space for expansion. At 650°C the above specimens released < 10% evolved gases; elements irradiated at c. 900°C ruptured and released 45-60% of gas. Failure in dispersion systems by swelling due to the accumulation of fission product gases has been considered by Keller[24], who describes two failure models (a) by creep after long-term steady state conditions and (b) by yielding where a sudden temperature rise produces stresses which exceed the U.T.S. of the matrix. The effect of increasing particle size in reducing the extent of fission fragment damage to the matrix has been demonstrated in measurements of hardness[25] and bend ductility[26]. Preliminary results[27] have shown that 28w/o UN in stainless steel irradiated at 1 100°C to 3-5a/o burn-up can be expected to show at least as good stability as 30w/o UO_2 in stainless steel irradiated to the same burn-up.

Irradiation of a series of 5w/o UO_2/graphite dispersions[28] with particle sizes in the range 40μm to 600μm showed that 2×10^{18} nvt at 90°C produced appreciable increases in elastic modulus and electrical resistivity and a decrease in thermal conductivity. The results illustrated the particle size effect and the important rôle of fission fragments in producing damage. Sayers[29] has examined dispersions of 50w/o fully enriched UO_2 (1μm) and UC_2 (20μm) in graphite irradiated to 0·5% burn-up at 600°C. Post irradiation dimensional changes were minor and the net effect was a volume decrease. Fractional gas release of 4-5% was measured from the UC_2 fuelled specimen.

Possible oxide matrices, on the grounds of adsorption cross-section, are beryllia, magnesia, alumina, silica and

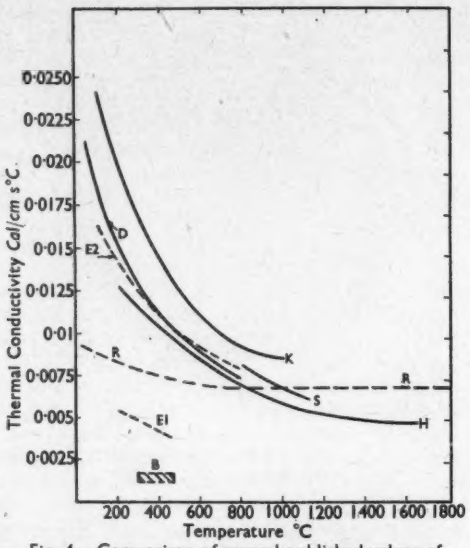

Fig. 4.—Comparison of several published values of the thermal conductivity of unirradiated and irradiated UO_2.

Unirradiated UO_2
K. Kingery, France et al, 1954. H. Hedge and Fieldhouse, 1956. D. Deem, 1960. S. Scott, 1958.

Irradiated UO_2
B. Berg et al, 1958. R. Robertson, Bain, et al, 1959. E. WAPD-22 experiment, 1958-60.
E1. 0·0035 in. diametrical clearance. E2. 0·000 in. diametrical clearance.

zirconia. The last two are, however, unattractive, being subject to radiation induced phase changes already referred to. Hot-pressed dispersions of 2w/o and 10w/o UO_2 in beryllia have been examined[30] after exposure to 3×10^{20} nvt at 250°C and 650°C respectively. At this dose the thermal conductivity had fallen to c. 20% of the original value; the linear dimensional change of c. 1% could be partially annealed at 900°C in vacuum. Compressive strength and Young's modulus showed a 30% decrease, the changes appearing to saturate at c. 5×10^{19}-5×10^{20} nvt. The particle size of the UO_2 in the 10w/o sample was $< 2\mu$m. Later work[31] has shown that for BeO/56w/o UO_2 (40μm) irradiated to $7{\cdot}3\times10^{12}$ nvt negligible property changes occurred at temperatures in the range 780°C-1 000°C: the microstructure of the BeO was unaffected and the fission release was low. For a dispersion of 100μm UO_2 in a 75% dense fused magnesia matrix 20% of the fission gas produced was released at 800°C[32]; this loss corresponds to the release expected by recoil and results indicate a high rate of diffusion of Xe in MgO above 600°C. The release from a dispersion of 100μm UO_2 in impervious alumina (containing some silica) was negligible at 800°C. Fission fragment damage has been reported to cause a 30% volume increase in Al_2O_3 after 0·9-10·8$\times10^{20}$ fissions/cc in an Al_2O_3/21w/o UO_2 dispersion[33].

The most promising ceramic carbide matrix appears to be silicon carbide; a dose of 10^{20} nvt (temperature not reported) gave $< 1\%$ linear expansion in both cubic and hexagonal SiC[34]. The changes were substantially annealed out at 1 200°C. Irradiation at 870°-950°C of siliconized SiC/UO_2 containing 4w/o U^{235} showed the fuel plate to be dimensionally stable[35]. Fission gas release was 0·001% of the total xenon produced.

Moderator Materials

Oxides

Beryllia has good high temperature strength and, on account of its high thermal conductivity has, for a ceramic oxide, exceptional thermal stress resistance. Pile irradiation can cause damage to the beryllia lattice by (a) displacements and (b) fission of the beryllium atoms. Reported results[30, 36, 37], not strictly comparable owing to lack of information on the exact conditions of exposure, show considerable variation. All observed dimensional changes measured at room temperature are slight (+0·25% for $\rho=3{\cdot}0$ was the maximum noted)[37] for doses up to 10^{21} nvt. Information on the room temperature compressive strength and Young's modulus shows a wide scatter, the largest reported decreases being 50% and 64% respectively[37]. The large observed drop in thermal conductivity may be expected to impair the thermal shock resistance; saturation at about 20% of the initial value probably occurs at c. 5×10^{20} nvt. Almost complete recovery of mechanical properties was achieved by annealing between 850° and 1 500°C[36].

Carbides

Beryllium carbide appears to be quite stable under irradiation; only small changes in the physical and mechanical properties have been reported. Poor oxidation resistance in air and water, however, restrict its field of application.

The damage caused in graphite by neutron irradiation is temperature dependent and is greatly decreased by raising the irradiation temperature above 30°C. On account of the weak Van der Waals forces between layers of atoms interlamellar carbon atoms produce a large increase in the c_o spacing and for a burn-up of 5 000 MWd/AT* and a graphite temperature of 30°C a 16% increase in c_o has been observed. There is a corresponding decrease in the a_o direction, the ratio $\frac{\Delta c}{c}\Big/\frac{\Delta a}{a}$ being about 10 : 1 for any dose. For a 5 000 MWd/AT burn-up and a graphite temperature of 400-500°C the c spacing increase is only 0.7%. The anisotropic behaviour of the lattice is reflected in the linear dimensional changes of polycrystalline extruded graphite, which has a high degree of preferred orientation. For burn-ups of 5 000 MWd/AT at 30°C the length changes are +3·1% perpendicular to and −0·8% parallel to the extrusion direction. At 400-500°C a small contraction is observed in both directions, an effect which persists at

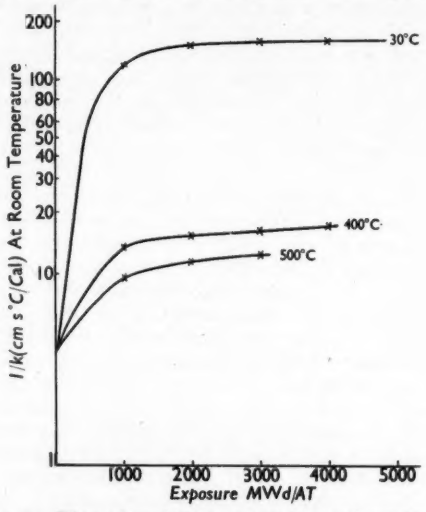

Fig. 5.—Effect of irradiation temperature and exposure on the thermal resistivity of CSF graphite.

* 1 MWd/AT=the amount of reactor radiation received by the sample during the time required for 1 ton of uranium adjacent to the sample to generate 1 MWd of fission energy.

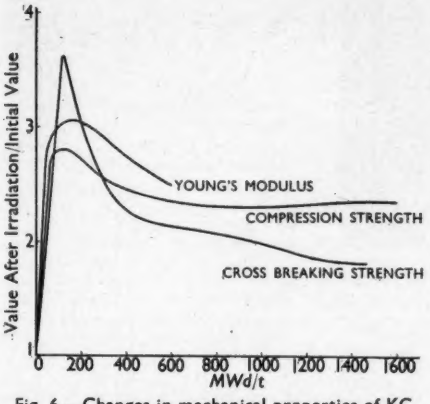

Fig. 6.—Changes in mechanical properties of KC graphite as a function of exposure at 30°C.

750°C. The thermal conductivity decreases with exposure; after 5 000 MWd/AT at 30°C it is only c. 2% of its original value (Fig. 5). For specimen temperatures of 750°C the decrease is only 50%. Stored energy accumulates during room temperature irradiation, and may after prolonged exposure be as high as 600 cal/gm[38]. Young's modulus and the compressive strength are approximately doubled (Fig. 6) and the hardness is greatly increased after 5 000 MWd/AT at 30°C. At this temperature the damage appears to saturate at 6 000 MWd/AT. Changes introduced by exposure at a given temperature may be annealed by heating to a higher temperature, the rate and degree of anneal being proportional to the temperature; by heating to above 2 000°C almost complete recovery is possible. Irradiation annealing has been observed in studies of stored energy, thermal conductivity and sample strength. The extent of radiation induced property changes in graphite is greater the higher the degree of development of the graphite structure present initially.

Control Materials

The function of these reactor components is achieved by the absorption of thermal neutrons in the core; of the two mechanisms of absorption, radiative capture of neutrons produces less damage than absorption with subsequent particle emission. This is the main disadvantage in the use of boron, where the large size of the resultant helium and lithium atoms causes considerable lattice strain. This can be to some extent overcome by the use of boron carbide which has a crystal structure sufficiently flexible to retain much of the helium produced. Of the boron containing compounds, the diboride shows the best helium retention, only 5% being released after 85% B^{10} burn-up at 260°C; particle fragmentation and dimensional changes were small[39]. There is little data available on boron nitride but it can be expected to show anisotropic expansion by virtue of its layer structure. Preliminary data[40] on dispersions of rare earth oxides in concentrations up to 30w/o in stainless steel indicate that these materials could be used for long-term, high-flux applications.

Structural Materials

The effect of neutron irradiation on the thermal conductivity, density and Young's modulus of some structural materials is given in Table 2[7, 41]. The irradiation temperature is not known but is probably below 100°C. Density decreases are small and are lower for materials of close packed structure. The density increase in vitreous silica is related[42] to the rearrangement of the structure to give a closer packing of the SiO_4 groups. It is accompanied by an increase in the low-temperature thermal conductivity[43]. The synthetic, high density modification of silica—coesite (ρ=3·01)—has been shown to have good radiation stability[44] which can be associated with its close packed structure. Room temperature thermal conductivity changes are much larger than density changes; Young's modulus is affected relatively little by irradiation at the temperature and fluxes quoted.

Reported results on the irradiation of diamond are of importance with regard to the use of covalent materials. Levy and Kammerer[45] observed a loss of crystallinity in 270 mesh diamond powder after c. 10^{21} nvt at <65°C. Earlier work[46] had shown a saturation of density change at c. 5×10^{20} nvt; the later results are explained[47] in terms of dose rate and irradiation temperature, that is the rate of introduction of defects is thought to override the annealing processes. Silicon carbide, having a diamond-type lattice, should be investigated in the light of the above observations. The level of energy stored in diamond and SiC is comparable to that in graphite[48]; on account of its relatively much greater specific heat, however, there is no catastrophic release of stored energy from SiC.

TABLE 2

EFFECT OF RADIATION ON SOME STRUCTURAL MATERIALS [7, 41]

Material	Integrated Flux (nvt)	Percentage Property Changes: Thermal Cond. (at 30°C)	Density (at 25°C)	Y.M. (at 25°C)
Al_2O_3 (single Xtal) ..	6×10^{19}	−50	−0·3	—
	16×10^{19}	—	—	<−10
	6×10^{20}	−66	−1·0	—
Al_2O_3 (sintered) ..	3×10^{19}	−42	−0·17	—
	16×10^{19}	—	—	<−10
	4×10^{20}	−77	+7·0	—
BeO	7×10^{19}	−33	+0·3	—
	6×10^{19}	—	−0·03	—
	$1·5\times10^{20}$	—	−0·04	—
	10^{21}	—	−1·0	—
MgO (single Xtal) ..	5×10^{19}	—	−0·1	—
	$1·2\times10^{21}$	—	−0·2	—
SiO_2 (fused)	6×10^{19}	—	+2·8	—
	10^{21}	—	+2·1	—
	7×10^{19}	—	+2·3	—
	16×10^{19}	—	—	<−5
	4×10^{20}	—	+1·2	—
Zircon	5×10^{19}	−81	−6·7	—
	16×10^{19}	—	—	−45
	3×10^{20}	—	−7·1	—
ZrO_2	16×10^{19}	—	—	<−10
TiO_2	6×10^{19}	−33	−0·5	—
	$3–6\times10^{19}$	—	—	<−5
	3×10^{20}	−61	−0·75	—
Spinel ($MgO.Al_2O_3$)..	7×10^{19}	−48	0	—
	4×10^{20}	−48	0	—
	6×10^{19}	—	−0·3	—
Cordierite ($2MgO\ 2Al_2O_3\ 5SiO_2$)	5×10^{19}	−73	—	—
	16×10^{19}	—	—	−27
	3×10^{20}	−73	—	—
SiC	5×10^{19}	—	−0·68	—
	8×10^{19}	—	−1·08	—

The changes produced in irradiated materials are dependent on the nature and amount of the incident radiation, the type of bonding in the material and the temperature of irradiation. In fissile materials the largest portion of the damage is caused by the high energy fission fragments, whose short range limits their effect to the fuel. In non-fissile materials the damage is produced by neutron bombardment. There is at present little systematic data on the effect of radiation on the properties of ceramics, and much of it is of limited application owing to the low irradiation temperatures employed. Further studies of the effect of high temperature irradiation and of annealing behaviour are required.

(*References at foot of following page*)

TRANSLATIONS

Réacteur d'Etudes Belge de Conception Originale—BR-2.

Maintenant presque fin prêt pour sa mise en route au Centre d'Etude de l'Energie Nucléaire, Mol, Belgique, est le BR-2, un réacteur d'essai de matières de 50 MW (th) de conception nouvelle. Sa forme est celle d'un sablier ou d'un diabolo, les canaux de combustible à l'intérieur du récipient de réacteur étant disposés de manière à former les lignes génératrices d'hyperboloïdes de révolution, c'est-à-dire ils sont biaisés de sorte qu'ils sont réunis ensemble au milieu, dans la région du noyau et évasés à leurs extrémités.

Propriétés des Matières pour Réacteurs.

Pour coïncider avec l'inauguration des nouveaux Laboratoires Berkeley de la Régie Centrale de Production d'Electricité de Grande-Bretagne, il s'est tenu une conférence internationale sur les propriétés des matières pour réacteurs et les effets des dégâts dûs aux radiations à Berkeley Castle que se trouve dans les environs. Ce numéro contient un court résumé de la conférence ainsi que les grandes lignes des facilités offertes par les nouveax laboratoires.

Instruments de Mesure de Radiations et de Protection

Une étude internationale des instruments conçus pour la mesure des radiations et pour la protection du personnel, y compris les instruments destinés à être employés de manière portative, sur établ, sur le sol ou montés sur muraille, ainsi que l'équipement d'échantillonnage dont le but de base est la mesure de la dose de radiation ambiente, la dose reçue par une personne, ou la contamination radioactive sur une personne ou son équipement.

Les dégâts aux céramiques dûs aux radiations

Les matières employées à l'intérieur de l'écran biologique doivent être en mesure de résister à de fortes doses de radiation sans que des modifications sérieuses se produisent dans leurs propriétés mécaniques. Vu que le comportement d'un solide est conditionné par sa structure cristalline des modifications de propriétés s'effectuent par la désintégration du réseau cristallin. Le présent article donne les grandes lignes des divers types de radiations et de leurs effets sur un nombre de céramiques diverses.

Neuartiger Belgischer Forschungsreaktor—BR-2.

Im Centre d'Etude de l'Energie Nucleaire, Mol, Belgien, steht ein neuartiger 50-MW (th) Materialprüfreaktor BR-2 kurz vor der Inbetriebnahme. Er hat Stundenglas-oder Diaboloform, und die Brennstoffkanäle innerhalb des Reaktorgefäßes sind so angeordnet, daß die Erzeugungslinien eines Rotationshyperboloids geformt werden, d.h. sie im mittleren Kernbereich zusammengebündelt und an den Enden ausgespreizt sind.

Eigenschaften von Reaktormaterialien.

Gelegentlich der Eröffnung der neuen Berkeley-Laboratorien des Electricity Generating Board fand im nahegelegenen Berkeley Castle eine internationale Konferenz über die Eigenschaften von Reaktormaterialien und die Wirkung von Strahlungsschäden statt. Diese Ausgabe enthält einen kurzen Überblick über die Konferenzergebnisse und eine Beschreibung der Laboratoriumseinrichtungen.

Instrumente für Strahlungsmessung und Strahlungsschutz

Ein internationaler Überblick der für Strahlungsmessung und Personenschutz bestimmten Instrumente, einschließlich solcher Geräte, die für Tisch-oder Wandbefestigung bestimmt sind. Es handelt sich um Apparate, deren Hauptzweck es ist, die Aktivität der Umgebung, die von einer Person empfangehen Dosis, oder die Radioaktivität einer Person bzw. deren Ausrüstung zu messen.

Strahlungsschäden in Keramischen Stoffen

Die innerhalb des biologischen Schildes benutzten Werkstoffe müssen große Strahlungsdosen ohne schwere Beeinträchtigung ihrer mechanischen Eigenschaften aushalten können. Da das Verhalten eines Festkörpers von der Kristallstruktur abhängt, werden Anderungen der Eigenschaften durch Störungen des Kristallgitters verursacht. Der vorliegende Artikel befaßt sich mit den verschiedenen Strahlungsarten in ihrer Einwirkung auf eine Zahl keramischer Stoffe.

Reactor de Investigacion Belga de Diseño Original—BR-2.

Casi listo para ponerse en funcionamiento en el Centre d'Etude de l'Energie Nucleaire, Mol, Bélgica es el BR-2, de 50 MW(th), un reactor de ensayado de diseño original. Es de forma de "reloj de arena," o "diabolo," siendo que los canales de combustible dentro de un recipiente de reactor están dispuestos de tal manera que forman las líneas generadoras de hiperboloides de revolución, es decir, están sesgados de modo que están juntados en el centro de la región del núcleo y descantillados en sus extremos.

Propiedades de Materiales de Reactor

Coincidiendo con el estreno de los nuevos Laboratorios de Berkeley del "Central Electricity Generating Board" (Consejo Central de Generación de Electricidad), tuvo lugar una Conferencia Internacional sobre las propiedades de materiales de reactor y los efectos de daño por radiación en el cercano Castillo de Berkeley. Este número contiene un corto sumario de la Conferencia, juntamente con un bosquejo de las facilidades en los nuevos laboratorios.

Instrumentos para la Medición de Radiación y Protección contra Ella

Un reconocimiento internacional de instrumentos diseñados para la medición de radiación ya la protección de personal, incluyendo instrumentos para uso portátil, en banco, en el suelo o montados en la pared, así como equipo de muestreo cuyo propósito básico es el de medir la dosis de contaminación del ambiente, la dosis recibida por una persona, o la contaminación radio-activa a una persona o a su equipo.

Daño por Radiación en Productos Cerámicos.

Los materiales mpleados adentro del escudo biológico deben ser capaces de hacer frente a grandes dósis de radiación sin cambios serios en sus propiedades mecánicas. Como el comportamiento de un sólido es regido por su estructura cristalina, los cambios de propiedades son efectuados por desarreglo de la red cristalina. El actual artículo bosqueja los diversos tipos de radiación y sus efectos sobre diversos productos cerámicos.

Radiation Damage in Ceramics — References

1. Wigner, E. P. *J. Appl. Phys.*, 17 : 857 (1946).
2. Des Cloizeaux, A. and Damour A. *Ann. Dhim. Phys.* (3), 59 : 357 (1860).
3. Barnes, R. S., and Greenwood, G. W. A/Conf. 15/P.29 (1958).
4. Slater, J. C. *J. Appl. Phys.* 22 (1951).
5. Dienes, G. J., and Vineyard, G. H. Radiation Effects in Solids. Interscience Publishers, New York and London.
6. Wittels, M. C., and Sherrill, F. A. *J. Appl. Phys.* 28 (1957).
7. Crawford, J. H., and Wittels, M. C. A/Conf. 15/P.679 (1958).
8. Wittels, M. C., and Sherrill, F. A. Phys. Rev. Letters V.3 N.4 (1959).
9. Gow, H. B. F., and Marsh, W. R. AERE R3194.
10. Eichenberg, J. D., *et al.* Fuel Elements Conf., Paris, 1957. TID 7546, Pt. 2.
11. Bain, A. S., and Robertson, J. A. L. *J. Nucl. Materials*, 1 (1959).
12. Robertson, J. A. L., *et al.* Nucl. Metallurgy, Vol. VI. A.I.M.M.P.E., New York, 1959.
13. Cohen, I., *et al.* W.A.P.D. 228.
14. Berg, K., *et al.* A/Conf. 15/P.141 (1958).
15. Ross, A. M., *et al.* C.R.F.D. 817.
16. Uranium Ceramics Data Manual DEG 120 (R).
17. Hare, A. W., and Rough, F. A. BMI 1491.
18. Bolomey, R., *et al.* NDA 2140-2.
19. Murray, P., and Williams, J. A/Conf. 15/P.318.
20. Weber, C. E., and Hirsch, H. H. A/Conf. 8/P.561.
21. White, D. W., *et al.* Fuel Elements Conf., Paris, 1957. TID 7546, Pt. 2.
22. Williams, J. Fuel Elements Conf., Paris, 1957. TID 7546, Pt. 2.
23. Barney, W. K., and Seymour, W. E. KAPL 1688.
24. Keller, D. L., *et al.* BMI 1408.
25. Feldman, M. J. Thesis, University of Tennessee, Met. Dept. (1956).
26. Valovage, W. D., and Siergiej, R. A. KAPL 1590.
27. Gates, J. E., *et al.* BMI 1446.
28. Kernohan, R. H. ORNL 1722.
29. Sayers, J., *et al.* AERE M/R 2546.
30. Gilbreath, J. R., and Simpson, O. C. A/Conf. 15/P.621 (1958).
31. Freas, D. G., *et al.* BMI 1484.
32. Stubbs, T. J., *et al.* AERE C/M 343.
33. Berman, R., *et al.* WAPD-T-1125.
34. Johnson, J. R. Am. Ceram. Soc. Bull., 36(9), 1957, Basic Science Res. Comm. Report.
35. Power Reactor Technology, Vol. 1, No. 2, 1958. U.S. Gov. Printing Office.
36. Clarke, F. J. P., and Williams, J. AERE M/M 229.
37. Elston, J., and Caillat, R. A/Conf. 15/P.1159 (1958).
38. Nightingale, R. E., *et al.* A/Conf. 15/P.614 (1958).
39. Hamman, D. J., and Schall, P. BMI 1406.
40. Anderson, W. K., and Dunning, D. N. *Prog. Nucl. Energy*, Series V, Vol. 2.
41. Clarke, F. J. P. Special Ceramics. Symposium at Brit. Ceram. Res. Assn. (Heywood and Co., 1960).
42. Simon, I. *Phys. Rev.*, 103, 1587 (1956).
43. Cohen, A. F., *J. App. Phys.*, 29 (1958).
44. Wittels, M. C. *Phil. Mag.*, 2, 1445 (1957).
45. Levy, P. W., and Kammerer, O. F. *Phys. Rev.* 100, 1787 (1955).
46. Crawford, J. H., and Wittels, M. C. A/Conf. 8/P.753 (1955).
47. Crawford, J. H. *Prog. Nucl. Energy*, Series V, Vol. 2.
48. Primak, W., *et al.* *Phys. Rev.* 103, 1184 (1956).

Personal

Appointments—U.K.

Mr. Ronald Edwards, deputy chairman of the Electricity Council since 1958, as chairman. He succeeds **Sir Robertson King,** who is retiring at the end of this year. **Mr. C. T. Melling,** full-time member of the Council since 1957, will be the new deputy chairman.

Dr. W. Wild, head of the radiation and solid state chemistry branch of the Chemistry Division, Harwell, as head of the division. He succeeds **Dr. R. Spence,** whose appointment as deputy director of Harwell was announced last year. **Mr. A. A. Smales,** head of the analytical chemistry branch of the division, has been given the status of a division head and will be directly responsible to the director of the establishment. His branch will continue to use the general administrative services of the Chemistry Division.

Mr. G. H. Greenhalgh, scientific attaché to the British Embassy in Stockholm, as resident nuclear energy representative on the U.K. Delegation to the European Communities, Brussels. He succeeds **Mr. D. H. Hill,** who is returning to the AEA to take up a post in the Reactor Group. Mr. Greenhalgh is also an AEA man and before going to Stockholm in 1956 was a member of the extra-mural research division at Harwell. His post at Stockholm is being filled by **Mr. William Drury,** of the Royal Naval Scientific Service.

Mr. J. H. Thornton, by the English Electric, Babcock and Wilcox, Taylor Woodrow Atomic Power Group, as group resident superintendent for the Sizewell nuclear power station. From 1957-59, Mr. Thornton was chief civil engineer on the Hinkley Point project and then assistant group resident superintendent.

Dr. M. Carl Walske, member of the U.S. delegation to the nuclear disarmament talks in Geneva, is the new London representative of the U.S.AEC. He succeeds **Dr. Louis Werner,** who returned to the States earlier this year (*Nuclear Engineering*, March, 1961). From 1951-56 Dr. Walske was deputy research director for Atomics International and from 1956-59 on the AEC staff at Los Alamos. He then went to Geneva. Dr. Walske takes up his new duties on June 28.

Lord Clitheroe, as a vice-chairman of Tube Investments.

Mr. J. H. Thornton.

Dr. M. Carl Walske.

Mr. Roy Snapp.

Mr. H. Etherington.

Mr. Ronald Edwards.

Dr. W. Wild.

Mr. A. A. Smales.

Mr. G. H. Greenhalgh.

Sir John Cockcroft, as chancellor of the Australian National University, Canberra. He succeeds **Viscount Bruce of Melbourne,** former Prime Minister of Australia and Minister for External Affairs.

Sir Edward Playfair, permanent secretary of the Ministry of Defence, as chairman of International Computers and Tabulators.

Mr. H. McNeill, managing director of Babcock and Wilcox, as chairman of the Water-Tube Boilermakers' Association. He succeeds **Mr. J. B. Woodeson,** chairman of Clarke, Chapman and Company, who has been in the chair since 1957. **Mr. C. J. Howard,** managing director of John Thompson Water-Tube Boilers, has been reappointed vice-chairman of the association.

Mr. E. W. Herrington, chief development engineer of the Turriff Construction Company, as engineer in charge of the mechanical and electrical service department of E. G. Irwin and Partners. From 1924 to 1958 Mr. Herrington was with the Ministry of Works and as senior engineer during the post war years was concerned with the development and construction of AERE, Harwell.

Viscount Knollys, chairman of Vickers, to the international advisory council for the international industrial conference to be held in San Francisco, September 11-15.

Mr. Norman Readman, managing director of the Consolidated Pneumatic Tool Co., as president of the Chicago Pneumatic Tool Co., New York.

Mr. S. H. Ireland, as assistant managing director of the Consolidated Pneumatic Tool Company; **Mr. L. S. Bright,** as financial director; and **Mr. A. O. Miller,** as a director.

Mr. L. A. Thomas, head of the materials and components division of the GEC Hirst Research Centre, as chief physicist.

Mr. R. H. Wilson, general sales manager of CIBA (A.R.L.), Cambridge, to the board.

Dr. Charles R. S. Manders, scientific officer with the Ministry of Defence, to the newly created post of scientific attaché to the British Embassy in Tokyo.

Mr. J. F. Widman, director and general manager, chemical division of Union Carbide, is shortly to take up a new assignment with Union Carbide International, and will be leaving the board of the U.K. company. While in Britain he has been responsible for the setting up and organization of the company's Hythe plant.

Queen's Birthday Honours

Mr. W. K. Gwynne, chairman and managing director of W. H. Allen and Co. and a director of Whessoe, **Mr. Sydney Albright,** chairman of Albright and Wilson, and **Mr. A. G. Clark,** chairman and managing director of Plessey Company, have been made Knights Bachelor; **Mr. E. Norton,** research director of Yarrow and Co., and **Mr. G. A. Whipple,** chairman and managing director of Hilger and Watts, have received the C.B.E., and **Mr. H. Gardner,** director of Glenfield and Kennedy (Holdings) has been awarded the O.B.E.

Appointments—Overseas

Mr. Roy Snapp, as vice-president of AMF in charge of the Washington office. Before joining AMF in 1957, Mr. Snapp was from 1947 to 1952 secretary of the U.S.AEC and later special assistant to Mr. Lewis Strauss, AEC chairman.

Mr. Harold Etherington, manager of the Allis Chalmers nuclear power department, Washington, as general manager of the company's atomic energy division. He is succeeded in the Washington post by **Mr. Henry C. Nickel,** assistant manager since 1959. Mr. Etherington, who was educated at Imperial College, London, has been with Allis Chalmers since 1937 and during the war worked on the Manhattan project. In the early '50s, as director of the naval reactor division at Argonne, he was responsible for the basic nuclear engineering design of *Nautilus*.

Mr. David G. Ott, senior nuclear engineer of the Internuclear Company, Missouri, as general manager of the company's newly created applied science division. For two years Mr. Ott was senior nuclear physicist on Internuclear's consulting staff attached to the SENN project, Italy.

Mr. C. F. Burnap, manager of military applications, Atomics International, as sales director for general products, and **Mr. P. R. Keep,** manager of applications engineering, as sales director for power systems.

Industrial Notes

The proposed merger of the **Superheater Company** into **International Combustion (Holdings)** is considered by the boards of both companies to be in the interests of both the shareholders and the employees. Due to the rationalization that has come about in the boiler manufacturing industry over the past few years the technical and commercial liaison between the two companies has grown considerably and Superheater in fact have tended to become increasingly dependent upon International Combustion for work. It is felt that a merger is the only way of ensuring the continual progress of both companies. **Combustion Engineering,** of New York, who hold 50·6% of the issued ordinary shares and some 43·4% of the issued "A" ordinary shares in Superheater, also approve of the proposal. IC have close technical liaison with CE and recently this liaison was assured for a further 10 years by an agreement providing for the payment of certain royalties and the allotment of 239 980 IC ordinary shares.

Engineers at the Rugby works of English Electric check the alignment of the rotor and motor of a CO_2 blower destined for the Hinkley Point nuclear power station.

Standby batteries for supplying power for essential services at Trawsfynydd nuclear power station during emergencies have been ordered from **Pritchett and Gold and E.P.S.,** of Dagenham, who have supplied similar equipment for the Hinkley Point station. Each of the two Trawsfynydd reactors will be equipped with a 420 V battery capable of putting out 520 kW for 20 min, by which time the standby diesel generating plant should be in operation. Emergency lighting requirements will be provided by a 240 V battery with an output of 175 kW for two hours, while switch-closing and tripping duties will be met by a 6 kW battery with a 3 h output.

Sir Roger Makins, AEA chairman, was principal guest at the opening on June 7 of **IBM United Kingdom's** computer centre at 58 Newman Street, London, W.1 (see "Industrial Notes," April, 1961).

A new factory is being built for **Taylor Controls,** of Walthamstow, London, at Stevenage, Herts. It will be a single-storey building with a floor area of about 40 000 ft², will cost £143 000, and should be ready for occupation by November.

Four 20-ton overhead cranes for the Dungeness nuclear power station are to be supplied by **Matterson,** of Rochdale.

Total expenditure of **DSIR** during the year 1960-61 is estimated at £12·2 million, compared with actual expenditure in 1959-60 of £10·3 million and £8·9 million in the previous 12 months, according to the Department's report for 1960. During the year it was decided to change the method of forecasting future financial needs. Now, instead of working to a set five-year plan, the DSIR will each year budget for the following year, with the approval of the Treasury and Parliament, make reasonable estimates for the next two years and less definite forecasts for the fourth and fifth years. In this way estimates can then be revised annually according to important unforeseen changes that may occur.

An exhibition of components made by **Aveley Electric** is being held at their Newman Street, London, W.1, premises. It was opened on June 12 and will run for six weeks.

A progressive reduction in staff employed by the extraction of metals group of the **National Chemical Laboratory** on work for the U.K.AEA is referred to in the laboratory's report for 1960, the reduction being concurrent with the change in emphasis from uranium to beryllium extraction technology. This work has been concerned with the extraction and concentration of the metal from concentrates containing 2-4% BeO derived from flotation from low grade ores.

SECA, the Swiss company formed by **Ateliers de Secheron** and **Ateliers des Charmilles,** both of Geneva, have been awarded a contract for the supply of the charge-discharge machine and related equipment for Dragon. It should be completed by the spring of 1962. Another recently announced order for the Dragon project is for equipment for the degassing and brazing of fuel boxes under vacuum at temperatures of about 1 600°C. It has gone to **Balzers Aktiengesellschaft,** of Liechtenstein, who have also received orders to supply furnaces for brazing metal to graphite and graphite to graphite without preliminary degassing.

A new company, **United Nuclear Corporation,** has been formed by the integration of the Nuclear Development Corporation of America (NDA), the nuclear fuels operation of Olin Mathieson Chemical Corporation, and the nuclear division of Mallinckrodt Chemical Works. Olin hold the majority of shares in the new company, which will have assets of approximately $25 million, annual sales amounting to about $30 million, and a staff payroll of 1 400. Emphasis of United Nuclear's activities will be in the sphere of irradiated fuel reprocessing. It is understood that Mallinckrodt plan to centre all their commercial work in the nuclear field with the new company including their relationships with Italatom in Italy and Nukem in Germany.

Drayton Regulator and Instrument Company have changed their name to Drayton Controls, and their telegraphic address becomes Draycon West Drayton Telex.

A contract to conduct tests of nuclear materials for **Siemens-Schuckertwerke AG,** of Erlangen, Germany, has been awarded to **Westinghouse Electric International.** The tests will be conducted at the Westinghouse testing reactor in Waltz Mill, Pennsylvania.

One of the automatic etching tanks at what is claimed to be the largest and most modern factory of its kind in the world for producing printed circuits, industrial nameplate and instrument panels. The plant is at Borehamwood, Herts, and is operated by the AEI company Printed Circuits in association with Millet, Levens. There are two of these tanks, each of which is electronically controlled, and they incorporate cleansing and degreasing operations for both before and after processing.

Technical Papers and Publications

U.S. REACTOR REVIEW

PAPERS recently delivered to the American Power Conference in Chicago included status reviews of gas-cooled, BWR and PWR systems.

GAS COOLED

The present status and future promise of gas-cooled reactors were reviewed in a paper by Peter Fortescue, Titus G. Le Clair and Corwin L. Rickard of the General Atomic division of General Dynamics. (This paper is reviewed in conjunction with a previous paper, given before the Joint Committee on Atomic Energy, in Washington, earlier in the year, by Dr. Frederic de Hoffmann, President of General Atomics).

U.S. interest in the gas-cooled reactor was first aroused in 1945 by the design study of the Daniels reactor, but slackened off during 1947-1956 and then revived. In fact so far as reactors under construction went, gas cooling predominated—largely due to the British and French programmes.

Metallurgical considerations and the use of natural U limited power density in the core; nevertheless, the largest and latest of the British consortia designs showed capital costs of about $280/kW and efficiencies as high as 33%. The natural outcome was the use of enriched oxide fuels and higher power densities and burn-ups, examples being AGR in Britain, and EGCR in the U.S., raising power densities to 1·5-3 kW/litre, gas outlet temperatures to 1 000-1 100°F (537-593°C) and burn-ups of about 10 000 MWd/t.

Practical limits to the outlet temperatures were still set by the metallic canning, and physical damage to the fuel limited the allowable burn-up. Attempts to advance beyond these limitations were the British-OEEC Dragon, the General Atomic HTGR, and the pebble-bed types as under development by Brown Boveri-Krupp, and studied in the U.S. by the Sanderson and Porter Co., and by ORNL.

Types of moderator other than graphite must not be overlooked; in particular the beryllium oxide moderated reactor MGCR—primarily intended for marine application—under development by their own organization (*Nuclear Engineering*, April, 1960, p. 173).

Peach Bottom

A major portion of the paper was devoted to the design of the 40 MW HTGR plant for the Philadelphia Electric Company, and 52 other utilities known as High Temperature Reactor Development Associates, at Peach Bottom, Pa., the engineer constructor being the Bechtel Corporation. The contract is for a fixed price of $24·5 million. The AEC provides $14·5 million for R and D and will waive full charges up to $2·5 million. PEC contributes the site and $8 million worth of plant.

HTGR has already been described in these pages (*Nuclear Engineering*, April, 1960, p. 172). Slight modifications have been made to the general parameters since the design was first published, and Table 1 gives the latest available figures.

TABLE 1
Main Parameters of HTGR

Thermal output	115 MW
Electrical output	40 MW
Thermal efficiency	34%
Core	
Diameter active	9 ft
Diameter over reflector	13 ft
Length active	7 ft 6 in
Length overall	11 ft 6 in
Weight of graphite, including reflector	67·2 tonnes
Coolant voidage in core	12·8%
No. of fuel elements	810
Dia. of fuel elements	3·5 in
Burn-up ($U^{233}+Th^{232}$)	70 000 MWd/t
Investment (U^{233})	150 kg
Investment (Th)	1 200 kg
Fissions/original fissile atoms	0·63
Graphite/uranium ratio	1 900
Max. fuel surface temp.	2 300°F (1 260°C)
Coolant, etc.	
Inlet temp.	660°F (349°C)
Outlet temp.	1 380°F (749°C)
Pressure	350 psi
Flow rate	80 000 ft³/min (480 000 lb/h)
Steam flow	367 000 lb/h
Steam	1 000°F (538°C)
Steam pressure	1 450 psia (102 kg/cm²)
Reactor pressure vessel dia.	14 ft
Reactor pressure vessel height	34 ft

Fig. 2.—Cutaway view of the HTGR graphite-canned fuel element.

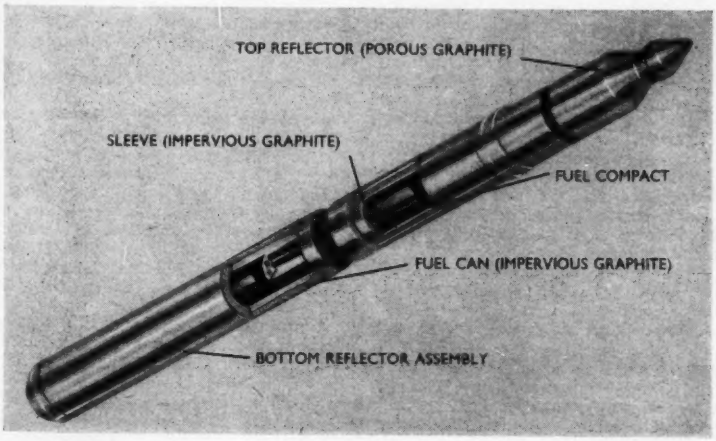

Fig. 1.—Section of HTGR fuel element about to undergo temperature tests.

A point of major interest, however, is that the development of the fuel elements appears to be a great deal more advanced than was the case when our original description was published. At that time, it was stated that, owing to the considerable development required, the HTGR would probably commence operation with metal-canned fuel elements, at reduced temperatures and outputs, changing to graphite canning at a later stage. From the statement of Dr. de Hoffmann before the Joint Committee, however, it seems that this is now unnecessary, since experiments on low permeability graphite and on fission product trapping have achieved sufficient success to enable Peach Bottom to operate at full temperature and pressure at start-up.

A further achievement listed was the development of pyrolytic coating particles of U-Th carbide fuels, giving them the property of holding-up gaseous fission products in the fuel compacts for several hours. Fuel compacts had been irradiated to ¾ of the expected burn-up, without significant dimensional changes (approx. 0·1%).

Testing in progress included a full diameter 4 ft fuel element, containing a complete fission product trap, which was under irradiation in a loop in the test reactor GETR at full temperature; a critical facility which had been in operation since June, 1960, and had proved the calculations for control rod worth to be correct within 5%; a half-scale flow model (illustrated in our "World Digest" pages for June, 1961, p. 228), and a control rod drive test facility.

Other HTGR Projects

A design study of a 150 MW plant is being undertaken, the ultimate user not being stated. A further 3-year research and development programme had recently been initiated for a plant in the 300-500 MW range for Empire State Atomic Development Associates, a group consisting of the seven privately owned New York State utilities, and General Atomic.

In conclusion, the authors stated that the HTGR concept promised to be competitive with coal in many areas, due to high temperatures and high power density giving reasonable capital costs, with overall efficiencies of 40%. Expected fuel costs, in sizes of 300 MW and above, were 1·2-1·7 mills/kWh.

BWR

The status of the boiling water reactor was examined by Dr. R. B. Richards, manager of engineering of the Atomic Power Equipment Department, General Electric Company.

The boiling water concept had commenced in 1953 with the first Borax and Spert experiments and continued with EBWR in 1955, the Vallecitos 5 MW plant in 1957, with a considerable increase (to a total of 190 MW) when Dresden went on the line in 1960. Progress made since the design of Dresden permitted the building of 400 MW plants for start-up in 1965 with a capital cost of $183/kW and a total generation cost of 6·76 mills/kWh at start-up, reducing to 6·46 mills/kWh for the second core.

Four main lines of BWR technology had been selected by General Electric for separate development; natural circulation, for low first cost and operational simplicity; forced circulation high power density, to obtain maximum power output from a given physical size; compact systems, to emphasize simplified design and economy; nuclear superheat, to improve heat rates. Obviously, as the separate development programmes progressed, there would be a gradual blending of many features; this had, in fact, occurred, and would continue until a single line of boilers and a single line of superheaters emerged.

TABLE 2
U.S.-built BWRs

Completed	Under Construction
Natural Circulation	
EBWR 5 MW	Elk River 20 MW
VBWR 5 MW	Humboldt Bay 50/60 MW
Forced Circulation	
(EBWR)	SENN (Italy) 150 MW
(VBWR)	Big Rock Point 50/75 MW
Dresden 180 MW	Kahl (Germany) 15 MW
	JPDR (Japan) 12 MW
Superheat	
	Pathfinder 62 MW
	Bonus 16 MW
	VESR 12·5 MW(th)

The general pattern of development by U.S. manufacturers is summarized in Table 2. EBWR and VBWR have provided prototypes for both natural and forced circulation plants; the VBWR, with a new high power-density core, will assist in the development of Big Rock Point and future high-density systems. Elk River and Humboldt Bay will give operational data on larger natural circulation systems. Pathfinder and Bonus will give the first operational data on superheat systems, while VESR (Vallecitos Experimental Superheat Reactor) will provide basic fuel irradiation and operational experience. When the stations under construction are completed there will be over 500 MW in operation; considerable extension of knowledge and experience will be obtained within the next two-four years.

Dresden

Dresden (*Nuclear Engineering*, October, 1960, p. 435) went on full power on June 29, 1960, and, until the shut-down on November 15, carried out routine operation up to full capacity, and has provided a great deal of information about large BWRs.

In the first place, it has established that a higher output is possible from a core of this size. Power flattening, by selective positioning of the control rods to compensate for flux perturbations due to void formation, has enabled full power operation with 452 fuel elements instead of the estimated 488; results of the testing programme indicate a reduction of peaking factor of 35% from that of a uniform core. Comparison of calculated and experimental results for various core and control rod configurations showed good agreement for the cold condition; hot results showed that calculations had been pessimistic, underestimating reactivity by about 1·5%. There is, therefore, more reactivity available for longer burn-up than expected.

Stability has been extremely good, not only in normal operation, but at almost double the rated steam void volume, and at 137% of rated primary flow—this limit being set by feed pump capacity, not by reactor stability. Transient stability was also good, under such conditions as recirculating pump and turbine trips, etc., while the anticipated overall ease of operation was confirmed. The load-following capability of the dual-cycle system was excellent, the plant responding to load fluctuations from 55%-100% of rated capacity without control rod adjustment. No difficulty was found in maintaining steam pressure to within ±1 psi. The plant heat rate (11 600 Btu/kWh) is about 2·5% better than the anticipated value.

Radiation levels are satisfactory. The Dresden turbine has not, for obvious reasons, yet been opened up, but in the case of Vallecitos, it was found that steam contamination was so slight that no limitation of working time was necessary. Neutron levels within the Dresden sphere are generally less than 2 mrem/h in the upper regions and less than 6 in the lower; gamma radiation in these areas is less than 2 mr/h.

Radiation levels in other parts of the plant are significantly attenuated a short distance from the turbine h.p. casing (300 mr/h) to 19 at the front turbine standard, 11 at the hotwell, and less than 0·5 at the feed pumps.

Initial experience with Zircaloy-2 showed that severe propagating failure could occur if water entered the element at high heat fluxes and central temperatures. Additional effort has been put into zirconium alloy development, and the Dresden peak fuel exposure has, so far, been approximately 1 650 MWd/t, or 16% of the design average.

Two major problems have come to light during operation, both connected with the control rod drives; first, through overstressing of a shear pin in the drive connection and, later, stress cracking of parts of the control rod blades, later replaced by different material (*Nuclear Engineering*, March, 1961, p. 98).

Today's Concepts

Following experience obtained, advanced BWRs can now be designed up to 500 MW gross electrical output with only reasonable extrapolation. Power densities have been increased from the 28 kW/l of Dresden to some 40 kW/l. Similarly fabrication techniques have been extended to permit vessels 16 ft diameter, weighing 500 tons (Dresden 12 ft dia., 300 tons). This will enable an increased output to be obtained from a station; a 500 MW dual cycle plant, for example, can be contained in a sphere 5 ft smaller than the Dresden sphere.

Single cycle plants will now dispense with the sphere, and employ the concept of *pressure suppression* in which the reactor and primary cooling system are housed in a concrete dry well, vented to a large pool of water, which condenses any steam released, thus relieving the pressure rise and retaining fission products.

Steam separation within the reactor vessel is a feature of present-day forced circulation designs, thus eliminating the large steam drum and its associated building space, structural work and shielding. The reduction in the amount of water at saturation pressure contained in the system is another advantage.

TABLE 3
BWR—Power Cost Trend

	Date of Technology				
	1959		1961		1967
System	300 MW dual	300 MW single	400 MW single	500 MW dual	500 MW single, superheat
Capital Cost $/kW	250	197	183	176	165
Power Cost (mills/kWh)					
Capital cost	5·00	3·95	3·65	3·52	3·3
Fuel cost (first core)	3·40	2·50	2·50	2·50	1·7
Operation and insurance	0·90	0·73	0·61	0·54	0·5
Total power cost	9·30	7·18	6·76	6·56	5·5
Do. with 2 mill equilibrium fuel	—	6·68	6·26	6·06	—

Capital costs are based on reference site, U.S. average labour rates, 14% fixed charges and 80% load factor.

Cost Trends

Table 3 compares reactor designs of the present (1961) technologies, with the AEC cost studies of 1959 (TID-8500), from which it will be seen that already it is possible to save some $53/kW on a 300 MW plant. Fuel costs with current technology should not be higher than 2·5 mills/kWh for the first core, 2.2 mills for the second, with equilibrium of 2 mills for subsequent cores. This assumes continuation of present AEC policies on ownership and costs of enriched uranium. It is considered that the work in progress on nuclear superheat promises capital cost reductions of $10-15/kW, and fuel cost savings of at least 0·2 mills/kWh.

PWR

The pressurized water reactor, or, to give it its preferred title, the CCWR (Closed Cycle Water Reactor) was reviewed by J. W. Simpson (Vice-president, Atomic Power Division, Westinghouse Electric Corporation), who pointed out that this type had already evolved through three generations. The Nautilus prototype, the first reactor to produce large quantities of usable power from the atom, commenced productive operation at NRTS in May, 1953, and Shippingport and Yankee could be considered the second and third generations.

Yankee (*Nuclear Engineering*, October, 1960, p. 466) could be considered a pioneer, not just a larger plant, and with its pellet-type oxide fuel in stainless steel canning, silver-indium-cadmium control rods, and simplified control mechanisms, represented real progress in design. Three other larger plants were now in the design state; SELNI (186 MW), SENA (259 MW) and Southern California Edison (375 MW); all represented

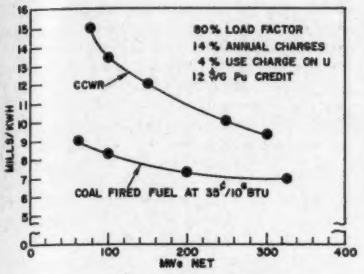

Fig. 3.—Effect of rating on the cost of plants. (Based on AEC study, 1959.)

considerable technical advances and reduction in capital cost. These plants represented fourth-generation technology and, even as they were pursued, the author looked forward confidently beyond them to 600-1 000 MW units. There were three main directions in which improvements might be looked for—increase in plant size; increase in rating of a given size; reductions in component costs.

The effect of size upon cost could be seen from the AEC study (TID-8516) significant data being summarized in Fig. 3. It

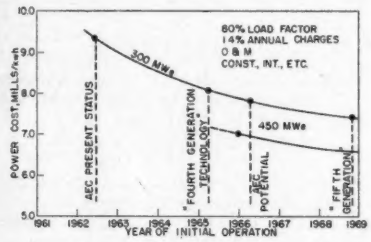

Fig. 4.—Economic potential of closed cycle water reactors. (Simpson.)

appeared that Yankee would equal—or even better—the 12 mills/kWh predicted for a 150 MW plant, so that the 1959 basis appears valid.

TID-8517 (Civilian Power Reactor Program Part II, Economic Potential and Development Program) predicted a power cost of 7·8 mills/kWh for a 300 MW unit to operate during 1966. Taking this as a starting point, the author has extrapolated to a "fifth generation" plant for 1968 and added an extra curve for a 450 MW plant. A 1 000 MW unit could be expected to show a saving of about 1·5 mills/kWh over a 400 MW unit.

A further approach to cost reduction, apart from the design of larger units, would be the raising of ratings of existing sizes, by the reduction of "hot spot" conditions, i.e., until the average more closely approached the limiting maximum conditions. As an example, a reactor designed with the Yankee first core hot spot conditions but with fourth-generation technology, could be rated at 190 MW, instead of its present rating of 120 MW.

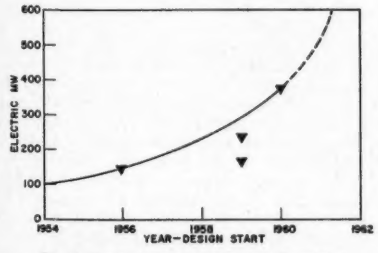

Fig. 5.—Increase in power rating allowable per single reactor. (Simpson.)

A fruitful field for cost reduction was a development programme for reducing thickness of fuel cladding, thus reducing the enrichment required and, consequently, fuel use charge and burn-up costs. At present, fuel technology did not permit using a clad thickness that would collapse on to the fuel pellets, under reactor pressure and temperature conditions. This, incidentally, would have to come if nuclear superheat was to be used to full advantage, since the desirable temperatures were in the creep range of most materials. While it might seem a small factor, it could be shown that, in a large reactor, reduction of stainless steel clad from 0·017 in to 0·007 in thick would give a saving of nearly 0·3 mills/kWh; in a 500 MW plant operating for 30 years at 80% load factor this would amount to some $30 M.

Savings on details were of the utmost importance. From the large pressure vessel to the small auxiliary circuit valve, it was necessary to press for the small cost reductions that, in the aggregate, made possible savings of millions of dollars. The same applied to the fuel. Cost reduction in chemical conversion, pellet manufacture or element fabrication might be even more important than component cost-cutting; the fuel bill for a plant might be several times the plant cost during its lifetime. Government charges for uranium also needed revision—natural U was available on the free market at prices which justified a substantial reduction in charges.

U.S.AEC

Recent Developments in the processing and ultimate disposal of high-level radioactive wastes. By Walter G. Belter (Sanitary Engineer, Division of Reactor Development, U.S.AEC). Paper presented at the Purdue Industrial Waste Conference, Lafayette, Indiana, May 2, 1961.

Liquid waste storage capacity in the U.S. would appear to be already more than half full, according to figures given in the introductory stages of this paper. Hanford, by far the largest disposal area, had, in 1959, a total tank capacity of 90 million gallons, and 52 million gallons of high-level waste. Comparable quantities for SRP and NRTS were 10 and 1·5 million gallons of waste in tank capacities of 23·5 and 2·7 million gallons respectively. While these figures would appear alarmingly high, the picture has changed considerably of late years; extraction processes now produce tens of gallons, instead of thousands, for each ton of uranium processed, and scavenging techniques, e.g., precipitation with nickel ferrocyanide for removal of caesium-137, have provided decontamination factors of 300-1 000, while calcium and strontium phosphates for the removal of strontium-90 have achieved decontamination factors of 450. Work is actively proceeding on electrolytic precipitation, solvent extraction and ion-exchange techniques for removal of fission products from waste solutions and the separation of fission products and residual bulk solids.

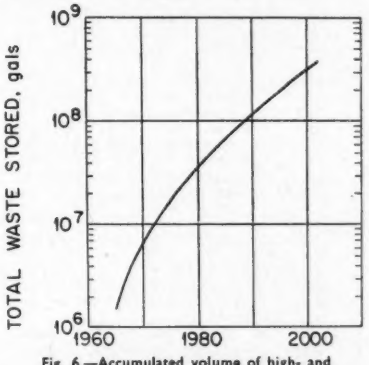

Fig. 6.—Accumulated volume of high- and intermediate-level waste. (Belter.)

Fig. 6 gives a forecast for future quantities of waste assuming a nuclear-energy economy with a capacity of 100 000 MW(th) by 1980 and 700 000 MW(th) by the year 2000. It is estimated that, with the current reprocessing methods, the amount of waste will be 36 million gallons by 1980—considerably less than the 50-55 million gallons at present in storage in Hanford.

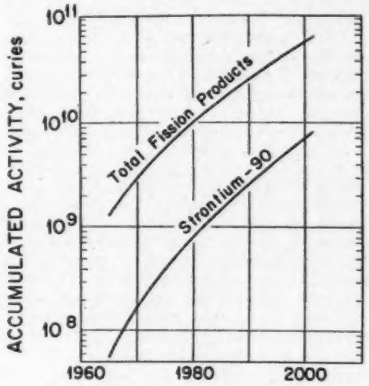

Fig. 7.—Accumulated radioactivity. (Belter.)

Of greater concern, however, is the actual amount of activity involved. By 1980, it is estimated that this waste volume of 36 million gallons will include some 800 megacuries of Sr-90 alone.

Storage Problems

Tank storage, at Hanford and Savannah River, costs $0·40-$0·45 per gallon, while stainless steel tank storage at NRTS costs from $2·63/gal for aluminium nitrate waste to $4·90/gal for zirconium waste. From the safety standpoint, life-expectancy of tanks was of the utmost importance; tests indicated that the corrosion rate of carbon steel tanks at 220°F was of the order of 10^{-5}-10^{-4} in/month.

Present research and development work in the disposal of high-activity wastes was proceeding in two different directions; conversion to solids and direct disposal of either liquids or solids into specified geological formations.

Conversion to Solids

Acid aluminium nitrate waste from processing fuels of the MTR type can be converted to granular alumina by fluidized-bed

calcination at 400-500°C. Initial research commenced at Argonne in 1955; subsequent work has been carried out at NRTS, and it is expected that a 60 gal/h pilot plant will operate with "hot" wastes during 1961-2. The nitrate solution undergoes a 6-8-fold volume reduction during the conversion to an oxide solid, which is then pneumatically transported to annular storage bins, cooled by forced air.

Radiant heat spray calcination in which waste is sprayed into the top of a tower, the walls of which are heated to 850°C, is being investigated at Hanford; the solid product may be stored as a fine powder or fused with additives into a glass.

"Pot calcination," being developed at ORNL, also shows promise. Acidic waste stored for three years to permit short-lived decay is evaporated and the resulting concentrated solution or slurry passed through an electrically heated pot where it is calcined at 700-900°C; the off-gases are passed through a downdraught condenser, and the resulting solution recycled. When the pot is filled it is sealed off and permanently stored; tests with synthetic Purex waste have established that the effluent from processing 6 tons of uranium could be calcined in one day, and contained in a single pot 10 in diameter and 6 ft high. A considerable amount of work remains to be done on this process.

Other methods under study include calcination in rotary ball kilns. A considerable amount of research is also proceeding on glassmaking additives, fixation in ceramic sponges, and the use of phosphites, phosphates, borates, etc., to obtain a more stable solid product.

Direct Disposal

Preliminary evaluations by the Committee on Waste Disposal of the Division of Earth Sciences, National Academy of Sciences—National Research Council and a sub-committee of the American Petroleum Institute indicate the possibility of direct discharge into certain geological formations. The major effort to date has been the field investigations in salt formation at Hutchinson, Kansas, by the Carey Salt Company, in conjunction with ORNL.

Another method under consideration is the disposal into deep (several thousand feet) permeable formations. Laboratory investigation and theoretical studies are being carried out by ORNL and the Bureau of Mines.

Finally, the disposal into impermeable shale by the hydro-fracturing process is being investigated by ORNL. Experimental work included the cutting of an existing well casing at 300 ft by a sand jet and pumping water down the well until the shale fractured at 2 300 psi, then pumping down a cement grout with a caesium tracer, after which bores were made at various distances from the well to investigate the plane of fracture, thickness and area of grout sheet, etc. A pilot plant is under consideration, using intermediate wastes.

Costs

The costs of these methods have not been established because of the preliminary nature of much of the work. Cost of tank storage on a "perpetual care" basis has been estimated at between 0·1 and 0·15 mills/kWh of electricity produced which, in an 8–10 mills/kWh economy, would approximate to 1–2% of generating costs. Costs of ultimate disposal currently under review are estimated to fall within this range and, if developments substantiate expectations, waste disposal should not constitute a major obstacle to the economics of nuclear energy.

The Metallurgy of Hafnium. (Naval Reactor Handbook Series.) Edited by D. E. Thomas and E. T. Hayes. (Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. $1.50.)

This report, in book format and running to 384 pp., is the third of the series to be devoted to the metallurgy of reactor materials; corresponding works on zirconium and beryllium having been published in 1955.

Commencing with the history and early work on the metal, the book then considers the nuclear properties, changes and uses of hafnium, a useful feature being tables of comparison with a number of other known neutron-absorbent materials. Non-nuclear uses of metallic hafnium and the oxide, silicate, carbide, nitride, boride of hafnium and the hafnate of calcium, are also discussed.

The extraction of the metal from ores, and the separation of hafnium and zirconium, are followed by reduction processes, refining, and the melting, fabrication and shaping of the metal, including extrusion and welding processes, as well as the practical aspects of machining.

The alloy systems of hafnium with some 25 other materials are reviewed, followed by a detailed consideration of the physical metallurgy and properties, analytical chemistry, and thermodynamic properties of the metal and its compounds. Appendices of engineering data and industrial hygiene are included, together with a list of contributing authors (no fewer than 43), a brief glossary, and names and subject indices.

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Descriptive List of complete series of Monographs available on request.

TEMPLE PRESS BOOKS

Bowling Green Lane, London, E.C.1

SRIA-17. Containment of Fragments from Runaway Reactor. By G. B. Huber, D. D. Keough, M. P. Stallybrass and N. R. Zabel (Poulter Laboratories), Stanford Research Institute. (Office of Technical Services, Department of Commerce, Washington 25, D.C. $1.50.)

Briefly summarized, this report deals with a series of tests on model reactors, with known amounts of energy released by chemical explosives, the behaviour being observed by high-speed photographs. By these means, it was possible to study the probable results of a full-scale reactor excursion at various powers, and to predict the order of energy of the fragmentation particles to be contained. A further series of experiments were made on the penetrating properties of blunt-nosed steel projectiles, using aluminium-killed steel plate of the type frequently used for reactor containment. The report contains extensive analysis of the results of the fragmentation tests, since certain properties, notably gravity, cannot be scaled down.

U.K.AEA

Authority Code No. E.3.1. United Kingdom Atomic Energy Authority Health and Safety Code. Site Emergency Control. (Health and Safety Branch, U.K.AEA, 11 Charles II Street, London, S.W.1.)

This is one of the series of Health and Safety Codes which is intended to cover the entire field of operations, including the safe design and operation of reactors, plants and laboratories, and the safe handling of materials. This code, which has no statutory force, lays down the broad outlines of responsibilities, pre-emergency planning for building, site, and district emergencies, and gives general guidance on external liaison and emergency reporting procedure. It is quite brief, and does not go into any detail.

AERE-Bib 130. Oxides of Europium, Gadolinium, Praseodymium and Samarium. Compiled by P. J. Jones (Metallurgy Division, AERE, Harwell). (H.M.S.O., 4s. 6d.)

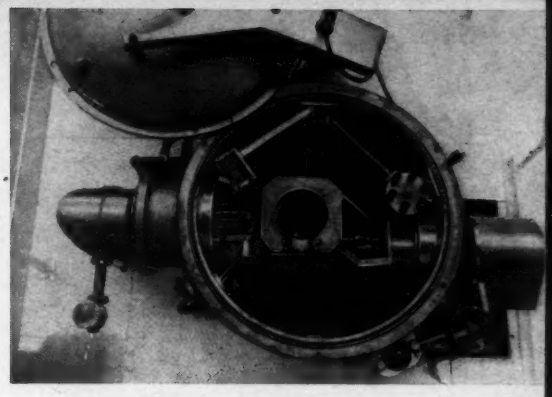
A bibliography on the subject, containing more than 180 references to published work and patents, with subject and author indices.

DEG Report 300 (CA) Vacuum Brazing with a Radio-frequency Induction Heater. By J. Leece, J. Bishop and C. C. McCormick. (Reactor Technology Branch, Capenhurst.) (H.M.S.O., 3s.)

A miniature textbook (although the authors modestly refer to it as a short study) on the technique of vacuum brazing, resulting from work done at Capenhurst as part of a programme to improve the vacuum standards of mass spectrometers. The approach is essentially practical, although fundamental principles are not ignored. In addition to a description of the apparatus and a number of examples of components constructed by this method, there are appendices giving particulars of 17 different types of solder with melting points from 550°C to 1 450°C together with data on a Johnson Matthey patent solder (titanium-cored silver-copper eutectic) for brazing ceramics to metals.

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.



View from above of the modified furnace installed at Sanderson Brothers and Newbould, Ltd.

Vacuum Furnace Capacity Increased

The "Edwards" vacuum furnace is well known to the industry, and has previously been described in these pages (*Nuclear Engineering*, September, 1956, p. 252). Two recent developments, however, are worthy of note; increased capacity and a new lid-lifting mechanism.

The "medium" model, formerly rated at 56 lb, is now suitable for charges up to 100 lb, and interchangeable coils for 28 lb, 56 lb, or 100 lb may be fitted. The lid, which formerly required an overhead hoist for its removal, is now lifted and slewed by a hydraulic mechanism operated by a hand pump on the furnace platform. The other features of this furnace—addition of up to one-third of the bulk charge and random selection of up to six alloying additions without breaking vacuum, dipping pyrometers, observation window with internal wiper and radiation shield, etc., remain unchanged. The illustration shows an overhead view of a furnace installed at Sanderson Brothers and Newbould, Ltd., of Sheffield.

(Edwards High Vacuum, Ltd., Manor Royal, Crawley, Sussex.)

1105

Fuel Element Testing

Sensitive leak-testing equipment for fuel elements, suitable for laboratory or production work has been developed by 20th Century Electronics, Ltd., and the first equipment has just been supplied to Japan. In essence, the unit consists of a mass spectrometer which detects leakage of a small amount of helium placed in the element before canning.

The element is placed within an enclosure, which is then evacuated to 10^{-5} mmHg, isolated from the pumping system and connected to the mass spectrometer which, tuned to the helium peak and calibrated against a leak of precisely known value, measures the pressure rise over a period of time. It is stated that the complete operation can be carried out in 10 min.

The pumping system is capable of sampling volumes up to 300 litres, so that,

The 20th Century Electronics leak-testing equipment.

if desired, it can be fitted to manifolds of testing enclosures, for batch production purposes.

(20th Century Electronics, Ltd., Centronics Works, King Henry's Drive, New Addington, Surrey.)

1106

Controlled Steering Castors

Manœuvring of heavy equipment is facilitated by a controlled castor recently developed. Fitted with modified Ackerman steering, a heavy chassis can be towed with 4-wheel steering from either end. Raising the tow-bar to a vertical position frees all four castors for independent manœuvring; lowering the tow-bar automatically restores the 4-wheel steering. A chassis 18 ft. by 6 ft, weighing 8½ tons, has been recently equipped with this gear.

Autoset controlled heavy-duty castor.

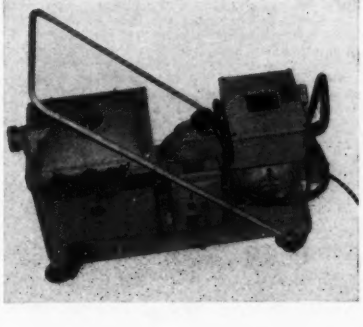
(Autoset (Production), Ltd., 72-79 Stour Street, Birmingham, 18.)

1107

Portable Air Filter

A modification of the Cimex absolute filter vacuum cleaner, as widely used throughout the U.K.AEA, is being supplied to Windscale in connection with the AGR. The experimental loop enclosures, normally inaccessible during operation, require complete ventilation after shut-down, before access is possible, and the modified machine is for recirculation and filtration of the air. The fan and motor are larger than standard, the velocity of the removed air in the region of the extraction hood being in the region of 3 000 ft/min. Approximately 100 ft³/min of air is extracted through 50 ft of 1½ in hose, and passed through a single "absolute" filter (0·2 μ particle size or 0·01% methylene blue penetration) and returned to the enclosure, or discharged, as required. The coarse (4 μ) filter normally used in the standard two-stage machine is not required, since the areas concerned have a low dust level. Lead shielding can be arranged on the filter unit, if desired.

Cimex portable filter unit.



(Cimex Fraser Tuson, Ltd., Cray Avenue, Orpington, Kent.)

1108

Hydraulic Stud Tensioner

Closure time of bolted-flange pressure vessels can be reduced—sometimes by as much as 75%—by hydraulic pre-tensioning of the studs, which eliminates the necessity for heating, enables precise control (within 2%) of elongation and, by eliminating torque, does away with the necessity for

The Diamond hydraulic tensioner unit for precise control of stud elongation to enable rapid removal and replacement of bolted heads on pressure vessels.

corrections for combined torque and tensile loading.

The Diamond stud tensioner (first mentioned in *Nuclear Engineering* for October, 1960, p. 456, in connection with the reactor for the N.S. *Savannah*) will apply hydraulic tension to any bolt or stud which has sufficient free length for the tensioner nut to engage, and sufficient clearance around the stud for the pedestal to stand. It is manufactured in capacities of 20 to 1 000 tons, for studs up to 8 in diameter. Damage to the stud by seizing, galling, or bending is prevented by self-aligning features and by centring rings of nylon or soft aluminium; a hardened nitralloy nut is used for the drawbar.

The necessity for high-pressure hydraulic hose connections is eliminated by the use of the hydraulic jack principle; compressed air, electrical, or hand pump operation can be arranged.

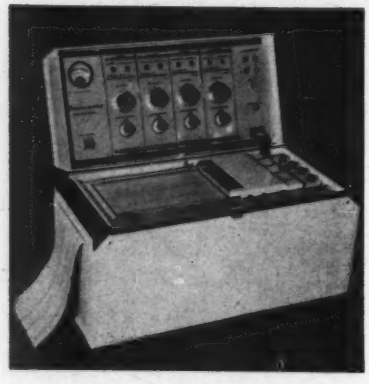
(Diamond Power Specialty Corporation, Lancaster, Ohio.)

1109

Direct-writing Recorders

Manufactured by Officine Galileo of Florence, a new range of industrial recorders is now being marketed in the U.K.

Direct-writing, by ink pen or hot stylus, these instruments may be used for recording any types of phenomena by suitable selection



A typical Officine Galileo 4-channel direct-writing recorder.

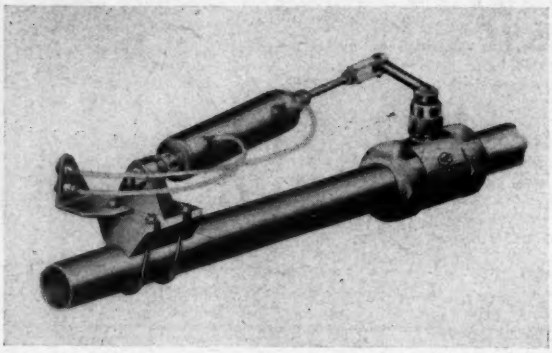
of interchangeable pre-amplifiers. Portable instruments are manufactured with two or four pens; rack-mounted on wheels, instruments are available as 2-, 4-, 6-, 8-, 16- or 32-channel units. Response time is 0·01 s, and chart speeds vary from 2·5 mm/s to 100 mm/s. Built-in photographic recorders may be supplied for recording phenomena with frequency components (200–800 c/s) above the range of direct-writing pens.

(Leland Instruments Ltd., 145 Grosvenor Road, Westminster, London, S.W.1.)

1110

Valve Operating Unit

A robust and simple power operating unit has been developed by Hydraulics and Pneumatics, Ltd., for use with their "Fullway" range of valves. The power unit, which may be supplied for pneumatic or low-pressure hydraulic operation, consists of an operating cylinder which is attached to the valve lever by a clevis, the fixed end being anchored to the pipe by a simple U-bolt fitting which also provides unions and anchorage for the operating lines. The unit



(Left) Hydraulics and Pneumatics packaged-type operating mechanism for "Fullway" valves.

is available for valves from ¼ in to 8 in nominal pipe size, and the remote control unit may be hand or solenoid operated. Adjustable orifice type speed limiters can be supplied.

(Hydraulics and Pneumatics, Ltd., Wulfruna Works, Villiers Street, Wolverhampton.)

1111

Auto Sample Changer

Comparison of a number of radioactive samples is facilitated by automatic presentation of the samples to the counting equipment. The new Tracerlab SC-100 Multi/Matic sample changer has accommodation for 50 samples of 1 in or 2 in diameter, which are placed in cups attached to a looped belt travelling in a horizontal plane and presenting the specimens one by one to the detector inside a lead castle, the cup being lifted from the belt and precisely positioned, giving good reproduction of results, and shielding the counting equipment from stray radiation from adjacent samples.

Programming arrangements allow for

(Below) The Tracerlab SC-100 automatic sample changer.

single counting of all samples, continuous repetitive counting of one—or all—samples, rapid selection of an individual sample, etc. The unit may be used with all existing designs of Tracerlab data printers, and Tracermatic scalers; it will accommodate all Tracerlab Geiger tubes, scintillation detectors, the TGC-14 beta counters and the

BRIEFLY . . .

Fire extinguishing powders for pyrophoric uranium, plutonium and thorium developed by U.K.AEA metallurgists, are being manufactured under licence by **John Kerr (Manchester), Ltd.,** of Kirkby Industrial Estate, Liverpool. The medium is a eutectic mixture of dry powdered inorganic chlorides and/or fluorides inert towards the metal concerned, and forming a fused skin around the metal particles to exclude air, fusion also absorbs latent heat and causes cooling. The burning material is contained rather than dispersed. **B262**

Recent improvements in the heavy (17 g/cc) tungsten alloy produced by **Kennametal Inc.,** Latrobe, Pat., U.S.A., now known as Kennertium, include the raising of the u.t.s. to 135 000 psi with 10% to 25% elongation and the compressive strength to 500 000 psi. **B263**

The Nobel Division of **Imperial Chemical Industries, Ltd.,** Silicones Department, Stevenston, Ayrshire, has introduced two new products to its range of "Silcoset" silicone rubbers. Silcoset 103 is intended for high temperature sealing, patching, caulking and potting, or it can be applied by a spray. "Silcoset" 104 can readily be bonded to primed metal surfaces. Both rubbers cure at room temperature, and four types of curing agent are available. **B264**

The Ozonair Engineering Co., Ltd., Ozonair Works, The Esplanade, Rochester, Kent, announced the development of a new type of power roof ventilator in sizes up to 10 000 ft³/min against 2·5 in w.g. **B265**

Spembly, Ltd., of New Road Avenue, Chatham, Kent, announce that by the use of their capacitor discharge welding equipment they are now able to offer mineral insulated thermocouples with earthed junctions in cable sizes as small as 0·25 mm (0·01 in) or insulated and sealed hot junctions in cables down to 0·5 mm (0·02 in) dia. **B266**

W. H. Rowe and Son, Ltd., Quayside Road, Bitterne Manor, Southampton, announced an introduction to their range of pinch valves (*Nuclear Engineering*, June, 1960, p.284). The new valve is 6 in in diameter, and initially will be available for hand operation only. A further improvement is the introduction of butyl rubber sleeves. **B267**

Nuclear-Chicago Corporation, 359 East Howard Avenue, Des Plaines, Illinois, U.S.A. (Continental Distributors, Ltd., 121 Earls Court Road, London, S.W.5), have designed a fourth interchangeable ion chamber for use with their "Cutie Pie" radiation monitor (*Nuclear Engineering*, March, 1961, p.126). The new chamber has three linear ranges, 0·25 r, 2·5 r, and 25 r, and may be used in X-ray beams as high as 200 r/min. **B268**

Recon (Pipelines), Ltd., Albert Drive, Sheerwater, Woking, Surrey, announce that their Vacuflex hose (*Nuclear Engineering*, July, 1960, p.331) is now obtainable in diameters up to 12 in, in lengths of 15 ft or more. **B269**

Johnson, Matthey and Co., Ltd., 73-83 Hatton Garden, London, E.C.1, can now supply zone-refined (50 ohm-cm n-type) germanium in ingots of 1 kg. They are also interested in the purchase of scrap germanium. **B270**

Nuclear Materials and Equipment Corporation (NUMEC), of Apollo, Pennsylvania, announce the successful deposition of a non-porous beryllia coating on particles of uranium dioxide, in layers—up to 100 μm thickness on 100 μm particles. Processes already developed and in commercial application include the deposition of zirconium oxides, alumina, molybdenum, niobium, vanadium, chromium, beryllium, tungsten and pyrolytic graphite. **B271**

new FD series of super-thin window gas flow counters.

(Tracerlab Inc., 1601 Trapelo Road, Waltham 54, Massachusetts, and Tracerlab S.A., Luchthaven Antwerpen, Antwerp.)

1112

Projection Microscope

The "Projectina" microscope, capable of magnification from 7-3 000, enables projection of images on to a ground glass screen with simultaneous examination through a built-in eyepiece.

"Projectina" projection microscope.

If required, the image may be projected on to a conference screen. Built-in lighting and polarizing equipment enables microscopy by transmitted or surface light, and macro/micro projection on bright or dark fields. Accessories such as a yarn or wire comparator enable two specimens to be reeled off simultaneously, for rapid comparison, while a special model with twin optical arrangements, enables direct comparison of two objects, e.g., metallurgical specimens, side by side on the same screen. A polaroid back is also available, for production of photographic records in about 1 minute.

(Peter J. Markham, Grosvenor Gardens House, London, S.W.1; R. G. Macfarlane, 8 Montgomerie Terrace, Skelmorlie, Ayrshire.)

1113

Self-priming Pumps

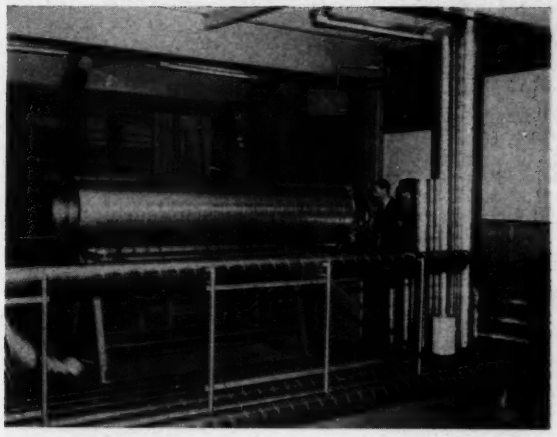
New designs of the Sykes self-priming pumps for sub-level operation include, in addition to improved impeller design, the extensive use of spheroidal graphite iron to eliminate electrolytic corrosion due to the use of dissimilar metals for impeller and housing. The design is particularly suitable where basement floors must be kept clear of gear, since the pump may be mounted at some height above sump level, without losing the self-priming feature. An open-type impeller is used so that slurries with high solids content may be passed; renewable wearing plates are fitted to the volute. The motor is totally-enclosed-fan cooled.

The new design of Sykes self-priming pump, which can be sling-mounted, independently of floor supports.

The unit is available in sizes of 2 in, 3 in, 4 in and 6 in suction and delivery; the 2 in size will handle 6 000 gal/h against a total head of 90 ft, or 4 000 gal/h at 100 ft head. The 6 in pump will handle 50 000 gal/h at 70 ft head, or 30 000 gal/h at 90 ft. Weights range from 6¼ cwt to 27 cwt.

(Henry Sykes, Ltd., 53b Southwark Street, London, S.E.1.)

1114



Typical "Airoduct" spiral-wound duct sections in the Hargreaves works. (*Bury Times* photo.)

Spiral-wound Ducting

Installation of a new machine of Scandinavian design, by Henry Hargreaves, has enabled them to extend their range of ductwork.

"Airoduct," as the new product is called, is produced by spiral winding of materials in coil form, resulting in a self-locking, rigid, air-tight tube which can show a saving of up to 40% in weight. The process can deal with materials such as mild steel, galvanized steel, stainless steel, plastics-coated steel, and aluminium, and sizes range from 3 in to 32 in diameter, in lengths up to 20 ft, thus reducing the number of joints required.

(Henry Hargreaves and Sons, Ltd., Lord Street, Bury, Lancs.)

1115

CATALOGUES

The *HP Journal*, published by the **Hewlett-Packard Co.**, 1501 Page Mill Road, Palo Alto, California, U.S.A., describes a new RF millivoltmeter, capable of operating up to 1 kMc/s.

The MilTherMatic steam trap, which has only one moving part, is described in a leaflet issued by **Midland Industries, Ltd.**, Heath Town Works, Wolverhampton.

The Multi/Matic sample changer is described in a catalogue received from **Tracerlab Inc.**, whose European distributors are Tracerlab S.A., Luchthaven, Antwerp, Belgium.

Pilkington Bros., Ltd., of St. Helens. Lancashire, have issued a catalogue on Chance-Pilkington shielding glass.

"Vital Statistics for Engineering Exporters," a booklet showing economic trends in important markets has been issued by **The British Engineers' Association**, 32 Victoria Street, London, S.W.1.

Midland Silicones, Ltd., 68 Knightsbridge, London, S.W.1, have issued a booklet entitled "Silastomer and Other MS Silicone Rubbers—a summary of the most important grades."

Carter "AM"-type hydraulic variable speed gears are described in a catalogue received from **Carter Gears, Ltd.**, Thornbury Road, Bradford 3, Yorks.

Silicon and germanium rectifiers and large power transformers are described in two catalogues received from **Hackbridge and Hewittic Electric Co., Ltd.**, Walton-on-Thames, Surrey.

Lists describing horizontal and vertical types of general purpose electrical furnaces have been received from **Wild-Barfield Electric Furnaces Ltd.**, Elecfurn Works, Otterspool Way, Watford By-Pass, Watford, Herts.

Suffolk Iron Foundry (1920) Ltd., Sifbronze Works, Stowmarket, Suffolk, have issued a new price list of Sifbronze oxy-acetylene welding products. Other leaflets describe stainless steel welding wires, Super Silicon No. 9 for cast iron welding, Sifbronze light flux, and S.I.F. silver solder and their complete range of cutting equipment.

Reference to their Silver Jubilee is made in a new publication from **Pyrotenax, Ltd.**, Hedgeley Road, Hebburn, Co. Durham, which illustrates a wide range of applications of Pyrotenax cable and lists the ranges of cable available.

Lodge Industrial Ceramics (Lodge Plugs Ltd.), Rugby, Warwicks, have issued a brochure giving complete technical data of their Sintox industrial ceramics. An abbreviated version has been produced for quick reference by designers.

Travelling wave tubes are described in a booklet issued by the **English Electric Valve Co. Ltd.**, Chelmsford, Essex. Other publications received include booklets on magnetrons, and a valve replacement index.

"Installing large-scale computers for nuclear calculations," a reprint from an IAEA paper by M. E. Drummond, is available from **IBM United Kingdom Ltd.**, Information Department, 101 Wigmore Street, London, W.1.

Royce hump-back conveyor furnaces for bright heat treatment and brazing in a protective atmosphere are described in a leaflet received from **Royce Electric Furnaces Ltd.**, Albert Drive, Sheerwater, Woking, Surrey.

The Pyrene range of derusting materials, including "Preperite" and "Pyroclean" are described in a leaflet received from the **Pyrene Co., Ltd.**, Metal Finishing Division, Great West Road, Brentford, Middx.

The **Hewlett-Packard Co.**, of 1501 Page Mill Road, Palo Alto, California, U.S.A. (London representatives Livingstone Laboratories, Ltd., Retcar Street, N.19), have issued an abridged catalogue of equipment.

A design manual for the metal O-rings, giving complete information on the design and application of the various types of O-ring, has been published by the **Advanced Products Co.**, 59 Broadway, North Haven, Conn., U.S.A.

Hand operated, mechanically and electrically operated counters are described in a booklet "Man Must Count," issued by **Trumeter Co. Ltd.**, Radcliffe, nr. Manchester.

Research and Control Instruments, Ltd., 207 King's Cross Road, London, W.C.1, have issued a new catalogue of radiation protection materials, equipment and accessories.

The new Tracermatic precision ratemeter is described in a list received from **Tracerlab Inc.**, 1601 Trapelo Road, Waltham, Massachusetts, U.S.A.

Prices and particulars of Philidas self-locking nuts are given in a commercial price list issued by **Whitehouse Industries, Ltd.**, Ferrybridge, Knottingley, Yorks.

A Buyers' Guide has been issued by the **British Pump Manufacturers Association**, 94-98 Petty France, London, S.W.1. In addition to a list of members, trade names and trade marks, there is a buyers' guide, classified under types and uses.

Orbits . . .

IT was a happy coincidence (if one happens to have that sort of mind) that almost at the time the CEGB held their conference on radiation damage of materials at Berkeley, the BBC decided to broadcast *King Richard II*. This, you may (or may not) remember, contains the following gem which, to us, has the authentic, despairing, just-before-the-battle-Mother atmosphere of the preparation for any conference . . . maybe we're wrong:—

". . . Gentlemen, go, muster up your men,
And meet me present at Berkley Castle.
I should to Plashy too;—
But time will not permit:— all is uneven,
And everything is left as six and seven."

"Plashy" obviously refers to conditions at the site—anyone who visited it in the early days of construction will agree.

Borderline Stuff

Tangent is occasionally shot at for allowing his attention to be diverted from the nuclear field into the electrical industry. The answer is two-fold. First, if it were possible to fix his sights firmly on a given object, these notes wouldn't be what they are (and what they are is anybody's guess) and, secondly, what business are we in? Generating electricity in large quantities is the nuclear world's *raison d'être*, from the immediate commercial angle, anyway. Remove this, and we might as well spend our money on man-carrying fireworks.

At any moment, someone with a pet project which does not fit into the power-generation field will get cross and quote Faraday's famous crack made to a lady who had queried the utility of his experiments. . . . "Madam, what use is a baby?" While admitting the profound truth of this, we would point out that the expense of bringing up a number of young children is more easily faced if an elder brother has landed a well-paid job. So be nice to the CEGB chaps, because one of these days they'll cut more ice than anybody else in this racket.

Pious Hope

And, before we start our Be-Kind-to-CEGB week, let us blot our copybook straight away with the pious hope that their nuclear laboratory policy will be just a little bit more (to quote Macbeth) ". . . bloody, bold, and resolute . . ." than the policy which underlay the designing of the "Super-Grid." About 1950, if our doddering memory serves us aright, the two-year-old British Electricity Authority commenced experimental work on a short length of 275 kV line. This was fine, so far as it went—but the Swedes were already using 380 kV, and the Americans had built an experimental length of 500 kV line. To choose this moment to start experiments with 275 kV seemed to us a typical example of planning for yesterday. All we could discover at the time was that it was Policy, coupled with a stern reminder of what happens to nasty little boys who ask stupid questions when Daddy is busy . . . maybe someone will now chastise us, and explain.

Heaven forbid that we should ask the CEGB to launch out rashly into all sorts of hare-brained schemes; taking risks with a nation's power supply is vastly different from taking chances in the laboratory. But excessive conservatism can cause as much trouble as over-rashness: the road policy of the M. of T. shows that.

Under the Spreading Chestnut Tree . . .

Way back (here we go again!) at a time when the popular conversational gambit was the need to hang that wrecker of hearth and home, the Kaiser, we commenced our engineering career with a company of General Engineers . . . and when we say "general," we mean it, since nothing from custom-built oat-rollers to refurbished traction engines came amiss to them. Life was then too full of getting caught up in belts, starting up machines with chuck keys in position and the stern business of a 54-hour week for 10s, to allow much time for introspection; it was many years later that we realized that this establishment was the up-to-date (not a machine older than 1880) version of the Village Blacksmith.

Since then, we've visited a good many factories, but they have, almost always, been of the most un-general type, producing large quantities of a specialized product, and we'd rather lost touch. It was not, in fact, until we attended the "open" day held at Lintott Engineering works at Horsham, that it was driven home to us that the general engineering works of today has progressed as far from the sort we knew as that, in its turn, had advanced from the forge under the chestnut tree. It was quite an experience to see glove-boxes, vacuum plant, beam-bending magnets, electronics cabinets and quite sizeable pressure vessels amongst the products, to see work being done to tenths of a thou, instead of tenths of an inch, and to see machine tools whose individual cost would have bought the old firm, lock, stock and barrel, twice over. To see the Apprentice Guild, with its own board of directors, replacing the gaffer's boot as the driving force behind the younger generation. One thing, only, remains unchanged; the we-do-anything spirit . . . "if it can be drawn, we can make it."

. . . "And I Live in a Ho-hole"

One of the handicaps of the nuclear industry is the inability to dispose of its waste as easily as other industries do, by building slag-heaps or washing it down the drains, or just kicking it around until it's lost. From an American paper, summarized elsewhere in this issue, it appears that improvements in separation techniques have reduced the volume of high-level liquid waste produced by several orders of magnitude. Nevertheless, the problem is one that still requires heavy research effort. One of the more promising methods seems to be hydro-cracking, in which a deep well in shale is used as a starting-point for forcing the products, in the form of a grout, into cracks produced in the rock stratum by hydraulic pressure.

Somewhere off the American coast, a band of stalwarts are engaged in "Operation Mohole," which involves (for some purpose which escapes us at the moment) drilling deep into the earth's crust. Couldn't the boys all get together, and the AEC acquire a second-hand hole when the Mo's have finished with it? They'll hardly want to take it away with them. Or are we over-simplifying things, as usual?

X Rears its Ugly Head

For some time now, the computer world has been comparatively quiet. Most computers seem to be fairly fully occupied nowadays and, apart from keeping the score for a 1 000 001-up darts match (and the computer had the sense not to let it be bounced into playing) there has been almost an absence of stunts.

A short time ago, however, a statement was issued that a computer was being used to design another computer. This, to our mind, is the wrong approach. As they have some human attributes, why not let this mechanized parthogenesis give way in favour of the normal human habits of courtship and marriage?

Some time ago, when the fashionable stunt was to make computers write love-letters, we pointed out that there was no authentic instance of a computer having written a love-letter to another computer, and we recently took expert advice in this matter from our favourite computer BLO U JAC who often does our verses for us (knowing, incidentally, that he's had his eye on a neat little analogue computer in the next lab. for a long time). As we expected, there was no difficulty at all. . . .

TO ANNA LOGGE

For you my printed circuits thrill
My cathodes brightly shine,
I'll ne'er know perfect *BLIS* until
You say that you'll be mine;
That all convention you'll defy
Make random access free,
And we shall meet and **MPY**
(NEWLINE: REPEAT: JUMP 3).

My little 1, my 1-0-1
Please won't you name the day?
Non-linear logic spurn, and shun
A mercury delay;
Though decadent I well may be
My patchless one, my queen,
I'll learn to speak in Binary
(STOP . . . Run DEBUG routine).

My valves are running hot today
And dim my mem'ry-store,
As YES-NO pulses leak away
From every ferrite core;
My BIT—this isn't just soft *SOAP*
I pulse for you throughout,
Please, tell me that I have some hope
(XX: XX: PRINT OUT).

Tangent

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